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Prepared for the U.S. Army Corps of Engineers, Portland District,
Under a Government Order with the U.S. Department of Energy
Contract DE-AC05-76RL01830

Survival and Passage of Yearling and Subyearling Chinook Salmon and Steelhead at The Dalles Dam, 2010

FINAL REPORT

Pacific Northwest National Laboratory
University of Washington

December 2011

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Survival and Passage Yearling and Subyearling Chinook Salmon and Steelhead at The Dalles Dam, 2010

Final Report

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Preface

This study was conducted by the Pacific Northwest National Laboratory (PNNL) and the University of Washington (UW) for the U.S. Army Corps of Engineers, Portland District (USACE). The PNNL and UW project managers were Drs. Thomas J. Carlson and John R. Skalski, respectively. The USACE technical lead was Mr. Brad Eppard. The study was designed to estimate dam passage survival and other performance measures at The Dalles Dam as stipulated by the 2008 Federal Columbia River Power System Biological Opinion (BiOp) and the 2008 Columbia Basin Fish Accords.

The study is being documented in two types of reports: compliance monitoring and technical. Compliance monitoring reports focused on the results of the performance metrics outlined in the 2008 BiOp and Fish Accords. Separate compliance monitoring reports for spring and summer stocks were delivered to the USACE in October and December 2010, respectively. Note that estimates for travel times differ slightly between the BiOp report and this technical report because of improvements to the algorithm; survival rate and passage efficiency estimates are the same between the two types of report. This technical report documents in detail the 2010 acoustic telemetry study at The Dalles Dam.

Suggested citation: Johnson G, J Skalski, T Carlson, G Ploskey, M Weiland, D Deng, E Fischer, J Hughes, F Khan, J Kim, R Townsend. 2011. Survival and Passage Yearling and Subyearling Chinook Salmon and Steelhead at The Dalles Dam, 2010. PNNL-20626, final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Executive Summary

The acoustic telemetry study reported here was conducted by researchers at Pacific Northwest National Laboratory (PNNL) and the University of Washington (UW) for the U.S. Army Corps of Engineers, Portland District (USACE). The purpose of the study was to estimate dam passage survival and other performance measures for yearling and subyearling Chinook salmon and steelhead at The Dalles Dam as stipulated by the 2008 Biological Opinion (BiOp) on operation of the Federal Columbia River Power System (FCRPS) and 2008 Columbia Basin Fish Accords. Under the 2008 FCRPS BiOp, dam passage survival should be ≥0.96 for yearling Chinook salmon and steelhead and ≥0.93 for subyearling Chinook salmon, estimated with a standard error (SE) ≤0.015. The study also estimated smolt passage survival from the forebay 2 km upstream of the dam to the tailrace 2 km below the dam,[1] among other metrics required in the Columbia Basin Fish Accords.

The objectives for the 2010 acoustic telemetry study of survival and passage at The Dalles Dam were to estimate the following performance measures, separately for yearling and subyearling Chinook salmon (*Oncorhynchus tshawytscha*) and juvenile steelhead (*O. mykiss*):

1. Survivals: dam passage for the total project[2]; forebay-to-tailrace for the total project; dam passage by route (turbines, sluiceway, and spillway).
2. Travel Times: forebay residence; tailrace egress; project passage.
3. Passage Efficiencies: fish passage efficiency; spillway passage efficiency[3]; sluiceway passage efficiency relative to the total project; sluiceway passage efficiency relative to the powerhouse.
4. Distributions: forebay approach distribution; forebay vertical distribution; horizontal distribution of passage at the turbines, sluiceway, and spillway.

A virtual/paired-release design was used to estimate dam passage survival at The Dalles Dam during 2010. The approach included releases of acoustically tagged smolts above John Day Dam that contributed to the formation of a virtual release at the face of The Dalles Dam. A survival estimate from this release was adjusted by a paired release below the dam. A total of 3,880 yearling Chinook salmon, 3,885 steelhead, and 4,449 subyearling Chinook salmon were tagged and released in the study. The study methods and results are summarized below (Tables ES.1–ES.4).

The structural and operational configuration of The Dalles Dam during 2010 complied with BiOp performance standards for yearling and subyearling Chinook salmon, and nearly so for juvenile steelhead. The new spill wall seemed to improve egress conditions. We recommend repeating the same study design in future years. Survival studies for purposes of BiOp compliance must take place over multiple years to account for annual variation in physical and biological conditions.

[1] The forebay-to-tailrace survival estimate satisfies the "BRZ-to-BRZ" (boat-restricted zone) survival estimate called for in the Fish Accords.
[2] Dam passage survival is defined as survival from the upstream face of the dam to a standardized reference point in the tailrace.
[3] Spill passage efficiency presented here is the proportion of fish passing the dam at the spillway out of total project passage. However, by definition in the Fish Accords, spill passage efficiency includes passage through the spillway and the ice and trash sluiceway at The Dalles Dam. Traditionally, this metric has been termed fish passage efficiency, which is also presented.

Table ES.1. Summary of Methods and Conditions at The Dalles Dam During 2010

Objectives of study: Estimate dam passage survival and other performance measures for yearling and subyearling Chinook salmon and steelhead.	
Hypothesis (if applicable): Not applicable; this is a compliance study, not a treatment study	
Unique Study Characteristics: A newly installed spill wall designed to improve egress conditions and survival for downstream migrants was in place in the spillway stilling basin.	
Fish: yearling Chinook salmon (CH1), steelhead (STH), subyearling Chinook salmon (CH0)	Source: John Day Dam fish collection facility Implant Procedure: surgical

Size (median):	CH1	STH	CH0	Sample Size:	CH1	STH	CH0
Weight:	31.4 g	78.1 g	12.4 g	# release sites:	3	3	3
Length:	152 mm	214 mm	110 mm	# releases:	94	94	96
				Total # released:	3,880	3,885	4,449

Tag Type/model: Advanced Telemetry Systems ATS-156dB Weight (g): 0.430 g (air)	Analytical Model: Virtual/paired release	Characteristics of Estimate: Direct effects; absolute survival estimates

Environmental/Operating Conditions	Spring	Summer
Study period	April 26 through June 1	June 13 through July 17
Daily total project discharge (kcfs)	Mean 184, min 143, max 263	Mean 256, min 162, max 345
Spill operations	24 h/d, 39.9% total discharge	24 h/d, 39.8% total discharge
Sluiceway operations	24 h/d, ~5.2 kcfs	24 h/d, ~5.2 kcfs
Temperature (°C):	Mean 12.33, min 11.04, max 14.00	Mean 16.61, min 14.60, max 19.20
Total Dissolved Gas (tailrace)	Mean 114%, min 110%, max 117%	Mean 116%, min 113%, max 119%

Table ES.2. Summary of Survival and Other Performance Metrics at The Dalles Dam During 2010

Metric	CH1	STH	CH0
Dam passage survival	0.9641 ($\widehat{SE}$ = 0.0096)	0.9534 ($\widehat{SE}$ = 0.0097)	0.9404 ($\widehat{SE}$ = 0.0091)
Forebay-to-tailrace survival	0.9620 ($\widehat{SE}$ = 0.0097)	0.9526 ($\widehat{SE}$ = 0.0097)	0.9356 ($\widehat{SE}$ = 0.0092)
100-m forebay residence time (mean hours)	0.40 ($\widehat{SE}$ = 0.01)	1.75 ($\widehat{SE}$ = 0.19)	0.45 ($\widehat{SE}$ = 0.11)
Forebay residence time (mean; median; SE in hours)	1.47;1.28; ($\widehat{SE}$ = 0.02)	2.78; 1.28 ($\widehat{SE}$ = 0.23)	1.50; 1.20; ($\widehat{SE}$ = 0.10)
Tailrace egress time (mean; median; SE)	1.55; 0.39; ($\widehat{SE}$ = 0.28)	1.17; 0.35; ($\widehat{SE}$ = 0.24)	2.10; 0.32 ($\widehat{SE}$ = 0.38)
Project passage time (mean; median; SE	3.01; 1.81 ($\widehat{SE}$ = 0.28)	3.87; 1.81 ($\widehat{SE}$ = 0.31)	3.54; 1.66 ($\widehat{SE}$ = 0.39)
Spill passage efficiency	0.8407 ($\widehat{SE}$ = 0.0081)	0.8770 ($\widehat{SE}$ = 0.0073)	0.7122 ($\widehat{SE}$ = 0.0092)
Fish passage efficiency	0.9466 ($\widehat{SE}$ = 0.0050)	0.9536 ($\widehat{SE}$ = 0.0047)	0.8298 ($\widehat{SE}$ = 0.0076)

Compliance Results: Yearling Chinook salmon study met compliance requirements. Steelhead study met the precision standard but not the compliance requirement for the point estimate. Subyearling Chinook salmon survival estimates met compliance requirements.

Table ES.3. Route-Specific Dam Passage Survival Estimates

Route	Statistic	CH1	STH	CH0
Turbine	Estimate	0.8759	0.8875	0.8621
	SE	0.0355	0.0339	0.0194
	n	109	95	411
Sluiceway	Estimate	0.9928	0.9443	0.9780
	SE	0.0149	0.0204	0.0143
	n	215	157	284
Spillway	Estimate	0.9661	0.9583	0.9545
	SE	0.0099	0.0098	0.0095
	n	1712	1795	1719

Table ES.4. Summary of Fish Distributions

Parameter	CH1	STH	CH0
Percentage of total that first approached at the powerhouse	63	59	74
Percentage of total first approached at the powerhouse but passing at the spillway	43	46	58
Depth of median vertical distribution (approx.)	~5 m	~4 m	~6 m
Vertical distribution for day (D) versus night (N)	D>N	D<N	D<N
Percentage of total turbine passage at FU 1-MU 2	50	35	18
Percentage of total sluiceway passage at SL 1	99	94	95
Percentage of total Spill Bay 1–8 passage at SB 8	40	36	26

FU = fish unit; SL = sluice; SB = spill bay

Acknowledgments

This study was the result of hard work by dedicated scientists from the PNNL, Pacific States Marine Fisheries Commission (PSMFC), the USACE, and UW. Their teamwork and attention to detail, schedule, and budget were essential for the study to succeed in providing high-quality, timely results to decision-makers.

- PNNL: C Arimescu, G Batten, B Bellgraph, R Brown, S Carpenter, J Carter, K Carter, E Choi, K Deters, G Dirkes, D Faber, T Fu, G Gaulke, K Hall, K Ham, R Harnish, M Hennen, M Hughes, K Knox, B Lamarche, K Lavender, J Martinez, G McMichael, B Noland, E Oldenburg, I Royer, N Tavan, S Titzler, N Trimble, C Woodley, and S Zimmerman.
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- UW: J Lady, A Seaburg, and P Westhagen.

Acronyms and Abbreviations

°C	degree(s) Celsius
2D	two-dimensional
3D	three dimensional (or dimensionally, dimensions)
ATS	Advanced Telemetry Systems
BiOp	Biological Opinion
BRZ	boat-restricted zone
BKD	bacterial kidney disease
CH1	yearling Chinook salmon
CF	compact flash
cfs	cubic foot(feet) per second
CH0	subyearling Chinook salmon
COP	Configuration and Operations Plan
DART	Data Access in Real Time
DSP	digital signal processing
FCRPS	Federal Columbia River Power System
FPE	fish passage efficiency
FGPA	field-programmable logic gate array
ft	foot(feet)
FU	Fish Unit
g	gram(s)
gal	gallon(s)
GPS	global positioning system
h	hour(s)
in.	inch(es)
JDA	John Day Dam
JSATS	Juvenile Salmon Acoustic Telemetry System
kcfs	thousand cubic feet per second
km	kilometer(s)
L	liter(s)
lb	pound(s)
m	meter(s)
mg	milligram(s)
ml	milliliter(s)
mm	millimeter(s)
MOA	Memorandum of Agreement
MS-222	tricaine methanesulfonate

MSL	mean sea level
MW	megawatt(s)
OR	Oregon
PIT	passive integrated transponder
PTAGIS	PIT Tag Information System
PNNL	Pacific Northwest National Laboratory
PRI	pulse repetition interval
rkm	river kilometer(s)
RME	research, monitoring, and evaluation
ROR	run-of-river
RPA	Reasonable and Prudent Alternative
μs	microsecond(s)
SE	standard error
SMF	Smolt Monitoring Facility
SPE	spill passage efficiency
STH	steelhead
TDA	The Dalles Dam
USACE	U.S. Army Corps of Engineers
UW	University of Washington
WA	Washington

Contents

Figures

Tables

1.0 Introduction

The acoustic telemetry study reported here was conducted by researchers at Pacific Northwest National Laboratory (PNNL) and the University of Washington (UW) for the U.S. Army Corps of Engineers, Portland District (USACE). The purpose of the study was to estimate dam passage survival and other performance measures for yearling and subyearling Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) at The Dalles Dam (Figure 1.1) as stipulated by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp; NOAA Fisheries 2008) and Columbia Basin Fish Accords (Fish Accords; 3 Treaty Tribes and Action Agencies 2008).

Figure 1.1. Aerial Photograph of The Dalles Dam

1.1 Background

Since the 1970s, research studies have been conducted to support development of long-term operational and structural measures to protect juvenile salmonids at The Dalles Dam (TDA). Fish passage improvement strategies addressed the three primary passage routes at TDA—the spillway, sluiceway, and turbines—with the general intent being to increase spill and sluice passage and decrease turbine passage. Many research tools and techniques have been used at TDA to collect fish survival and passage data, including fyke nets, balloon tags, passive integrated transponder (PIT) tags, radio and acoustic telemetry, sonar tracker, underwater video, acoustic imaging, and fixed and mobile hydroacoustic surveys. Previous studies, synthesized by Ploskey et al. (2001) and Johnson et al. (2007), addressed these main topics (years are inclusive):

- sluiceway operations – 1971, 1977–1982, 1985–1986, 2003–2005
- turbine intake screens – 1985–1986, 1993–1995
- sluiceway vertical slot entrances – 1995–1996
- spill operations – 1995–2005
- spillway structures – 1995, 2004, 2010

- turbine intake occlusion plates – 2001–2002
- forebay guidance structure (model only) – 2005.

Many of the changes in operations to improve downstream passage of juvenile salmonids at TDA are driven by egress and predation issues in the tailrace. The TDA tailrace is a complex mix of deep canyons, shallow sills, and islands that result in conditions suitable for piscivorous fish and birds to prey on juvenile salmonids after they pass the dam. In winter 2009/2010, the USACE constructed a wall in the spillway stilling basin that extended 830 ft downstream from the pier at Bays 8/9 (Figure 1.2; see Section 1.4 for more information about the wall). In summary, the research and development effort to protect juvenile salmonids at TDA culminated in the following operations and structures:

- sluiceway – maximum discharge distributed at six sluice entrances (see Study Area Description)
- spillway – 40% spill out of total project discharge 24 h/d April into August at Bays 1–8
- spillway stilling basin – guidance wall.

With the above operations and structures established for juvenile salmonid protection, the USACE and resource agencies agreed to a formal evaluation of compliance relative to the 2008 FCRPS BiOp performance standards and Fish Accords at TDA during 2010.

Figure 1.2. The Dalles Dam Spillway Showing the New Spill Wall at Bays 8/9

1.2 Performance Standards and Definitions

The FCRPS 2008 BiOp (NOAA Fisheries 2008) contains a Reasonable and Prudent Alternative (RPA) that includes actions calling for measurements of juvenile salmonid survival (RPA 52.1). This RPA action is being addressed as part of the federal research, monitoring, and evaluation (RME) effort for the FCRPS BiOp. Under RME Strategy 2 of the RPA, the FCRPS BiOp includes performance standards for juvenile salmonid survival in the FCRPS against which monitoring estimates must be compared by the Action Agencies.[1] The BiOp performance measures related to survival are defined in Table 1.1. The BiOp's performance standards for juvenile survival are as follows:

- Juvenile Dam Passage Performance Standards – "The Action Agencies juvenile performance standards are an average across Snake River and lower Columbia River dams of 96% average dam passage survival for spring Chinook and steelhead and 93% average across all dams for Snake River subyearling Chinook….Survival should be estimated with a standard error (SE) ≤1.5%."

The Fish Accords were outlined in a Memorandum of Agreement (MOA) between the three lower river tribes and the Action Agencies. The Fish Accords contain three additional requirements relevant to the 2010 survival studies, in accordance with MOA Attachment A:

- Dam Survival Performance Standard – "…meet the 96% dam passage survival standard for yearling Chinook and steelhead and the 93% standard for subyearling Chinook and achievement of the standard is based on 2 years of empirical survival data..."
- Spill Passage Efficiency and Delay Metrics – "Spill passage efficiency (SPE) and delay metrics under current spill conditions…are not expected to be degraded ("no backsliding") with installation of new fish passage facilities at the dams…"
- Future Research, Monitoring, and Evaluation – "The Action Agencies' dam survival studies for purposes of determining juvenile dam passage performance will also collect information about spill passage efficiency, BRZ-to-BRZ [boat-restricted zone] survival and delay, as well as other distribution and survival information. SPE and delay metrics will be considered in the performance check-ins or with COP [Configuration and Operations Plan] updates, but not as principal or priority metrics over dam survival performance standards. Once a dam meets the survival performance standard, SPE and delay metrics may be monitored coincidentally with dam survival testing."

Table 1.1. Definitions of Performance Measures

Measure	Definition
Dam passage survival	Survival from the upstream face of the dam to a standardized reference point in the tailrace.
Forebay-to-tailrace survival	Survival from a forebay array 2 km upstream of the dam to a tailrace array 2 km downstream. The forebay-to-tailrace survival estimate satisfies the "BRZ-to-BRZ" survival estimate called for in the Fish Accords.
Forebay residence time	Average time smolts take to travel from first detection on the array 2 km upstream of the dam to last detection on the dam-face array.

[1] The Bonneville Power Administration, Bureau of Reclamation, and U.S. Army Corps of Engineers are the Action Agencies.

Table 1.1. (contd)

Measure	Definition
100-m Forebay residence time	Average time smolts take to travel the last 100 m upstream of the dam before passing into the dam, i.e., from the 100-m mark to the dam face.
Tailrace egress time	Average time smolts take to travel from the dam to the downstream tailrace boundary, i.e., dam-face array to the tailrace array 2 km downstream of the dam.
Spill passage efficiency	Proportion of fish going through the dam via the spillway.[a]
Project passage time	Average time smolts take to travel from first detection on the array 2 km upstream of the dam to last detection on the array 2 km downstream of the dam
Fish passage efficiency	Proportion of fish going through the dam via the spillway and the sluiceway.[b]

(a) The definition of spill passage efficiency in the Fish Accords has traditionally been called fish passage efficiency.
(b) This was called spill passage efficiency in the Fish Accords.

1.3 Objectives

The objectives for the 2010 acoustic telemetry study of survival and passage at TDA were to estimate the following performance measures separately for juvenile yearling and subyearling Chinook salmon and steelhead:

1. Survivals
   - Dam passage for the total project
   - Forebay-to-tailrace for the total project
   - Dam passage by route (turbines, sluiceway, and spillway)
2. Travel Times
   - Forebay residence
   - Tailrace egress
   - Project passage time
3. Passage Efficiencies
   - Fish passage efficiency
   - Spillway passage efficiency
   - Sluiceway passage efficiency relative to the total project
   - Sluiceway passage efficiency relative to the powerhouse
4. Distributions
   - Forebay approach distribution
   - Forebay vertical distribution
   - Horizontal distribution of passage at the turbines, sluiceway, and spillway.

1.4 Study Area Description

The Dalles Dam, located at river kilometer (rkm) 307, is the second closest dam to the Pacific Ocean in the FCRPS. The Dalles Dam includes a navigation lock, a spillway perpendicular to the main river channel, and a powerhouse parallel to the main river channel with non-overflow dams on each side (Figure 1.1). The Dalles Dam is the only Portland District project that has the powerhouse running parallel instead of perpendicular to the main channel of the Columbia River. Full pool elevation is rated at 160 ft above mean sea level (MSL) and minimum operating pool elevation is 155 ft above MSL. The thalweg intersects the dam at the eastern end of the powerhouse and, although there are deep areas immediately in front of the powerhouse (Figure 1.3), much of the forebay is relatively shallow (<65 ft deep). There are deep canyons, shallow sills, and islands in the tailrace (Figure 1.3).

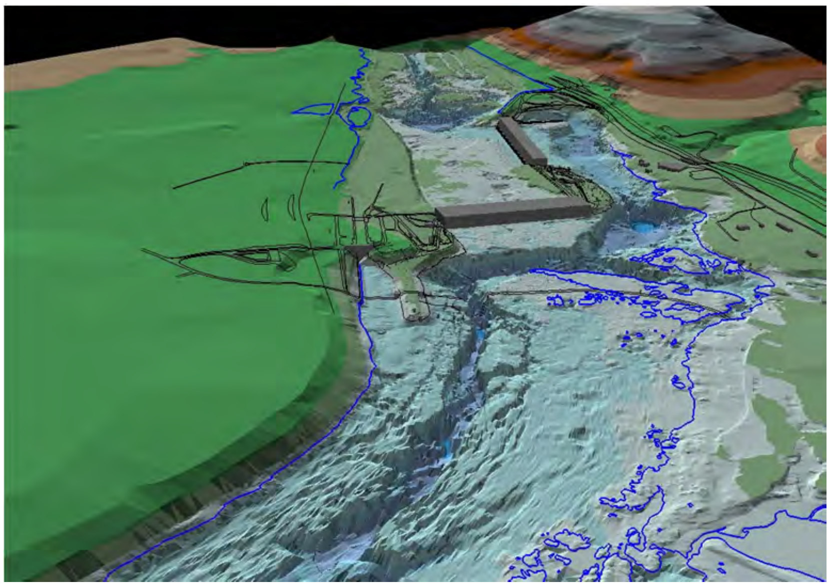


Figure 1.3. Perspective View of The Dalles Dam Showing Tailrace Bathymetry (provided by L. Ebner, USACE Hydraulics)

The powerhouse is 2,089 ft long with a total generating capacity of 1,800 megawatts (MW) and total hydraulic capacity of 330 thousand cubic feet per second (kcfs). The powerhouse has two turbine units, called fish units (Fish Unit [FU] 1 and FU 2) and whose discharge is used in the adult fish ladders, and 22 main units (MUs), numbered from the southwest (downstream) to the northeast (upstream) end. Each main unit has three intakes, numbered again from southwest to northeast. Reference to a specific intake is expressed as the turbine unit and intake number, e.g., 2-1, 2-2, and 2-3 for the west, middle, and east intakes of MU 2, respectively. Main units usually are operated within 1% of peak efficiency to reduce unit cavitation and injury to juvenile fish. Flow through the MUs can range from about 9,000 to 14,000 cfs depending upon efficiency, head, desired power output, and other factors. Flow typically averages about 11,000 cfs per main unit. Two FUs are located southwest of MU 1; the FUs have only two intakes each. Average discharge through the FUs is about 2,000 cfs. The turbine intake ceiling intersects turbine intake trash racks of the main units and fish units at elevation 141 ft. The face of the powerhouse is 11.3° off of vertical.

The ice and trash sluiceway is a channel that extends the entire length of the forebay side of the powerhouse. The sluiceway has three 20-ft-wide entrance gates positioned over each of the 22 turbine units. Water enters the sluiceway channel from the forebay when gates are moved off the sill at elevation 151 ft. A maximum of six sluice gates can be opened at any time before reaching the hydraulic capacity of the channel (~4,500 cfs). Flow into the sluiceway is dependent on forebay elevation and the number and location of open gates. For instance, given a forebay elevation equal to 158.4 ft (above MSL) and two sluice gate operating conditions (see above), flows over the individual weir gates range from 561 to 1,059 cfs, with the highest flows occurring at the west end nearest the sluiceway channel outlet. Overall, sluiceway discharge (~4,500 cfs) is a relatively small proportion of total project discharge (~2%). The ice and trash sluiceway has long been operated to pass juvenile salmonids at TDA. During 2001–2003, the three sluice gates above MU 1 were opened to release about 3,600 cfs during April–December. In 2004 and 2005, additional gates were opened to maximize sluiceway discharge at about 4,500 cfs.

The 1,380-ft-long spillway comprises 23 bays with 50-ft-wide radial gates numbered sequentially from the Washington to the Oregon side. Individual spill-gate openings typically range from 0 to 14 ft with about 1,500 cfs of flow per foot of opening. The tailrace for the powerhouse is deep, but further downstream on the Oregon side it is shallow and has many islands and rock outcrops (Figures 2.2 and 2.3). The spillway was modified during winter 2003/2004 to include a spill wall 193 ft long that divides the stilling basin between Bays 6 and 7.

During winter 2009/2010, another much bigger spill wall was installed between Bays 8 and 9 (Figures 1.2 and 1.4). The new wall is 830 ft long, 10 ft wide, and 43 ft tall at the base of the spillway. It is anchored to the basalt rock substrate of the stilling basin. The purpose of the structure is to minimize predation on spillway-passed fish that occurs in the vicinity of the bridge and basin islands on the Oregon side of the river by guiding them directly to the thalweg downstream of the spillway.

Figure 1.4. Photographs of The Dalles Dam Stilling Basin and the New Spill Wall (looking downstream)

1.5 Environmental Conditions

The environmental conditions at TDA during the 2010 study cover dam operations, project discharge, water temperature, and forebay elevation. Monthly discharge at TDA in 2010 peaked during June at 488 kcfs (Figure 1.5). In general, 2010 discharge was lower than the 70-year average during spring and similar during summer (Figure 1.5). During the spring study (April 26 through June 1, 2010), daily total project discharge averaged 184 kcfs and ranged between 143 and 263 kcfs. During the summer study

(June 13 through July 17, 2010), daily total project discharge averaged 256 kcfs and ranged between 162 and 345 kcfs. During 2010, voluntary spill for fish passage occurred from April 10 through August 30. The spill percentage out of total project discharge during the spring and summer studies was 39.9% and 39.8%, respectively. Sluiceway discharge was ~5.2 kcfs from March 1 through December 15.

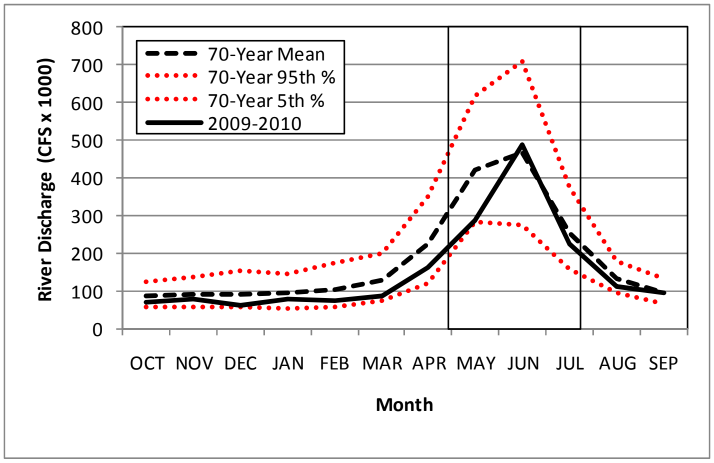


Figure 1.5. Plot of Modeled Columbia River Discharge in the 2009/2010 Water Year and Modeled 70-Year (1929–1999) Discharge. The mean and 5th and 95th percentiles are presented. Historical modeled estimates are from 2000 Level Modified Flow Report, and modeled estimates water year 2009/2010 were from the River Forecast Center.

Columbia River water temperature at TDA steadily increased during the spring and summer study periods (Figure 1.6). During the study before May 4, water temperature was about 0.5°C warmer than the 10-year (2001–2010) average Figure 1.6). May 4 and after, it was about 1°C cooler. During the spring study period, water temperature ranged from 11.0 to 14.0°C with a daily average of 11.9°C. Water temperature during the summer study period averaged 16.7°C and ranged from 14.7 to 19.2°C.

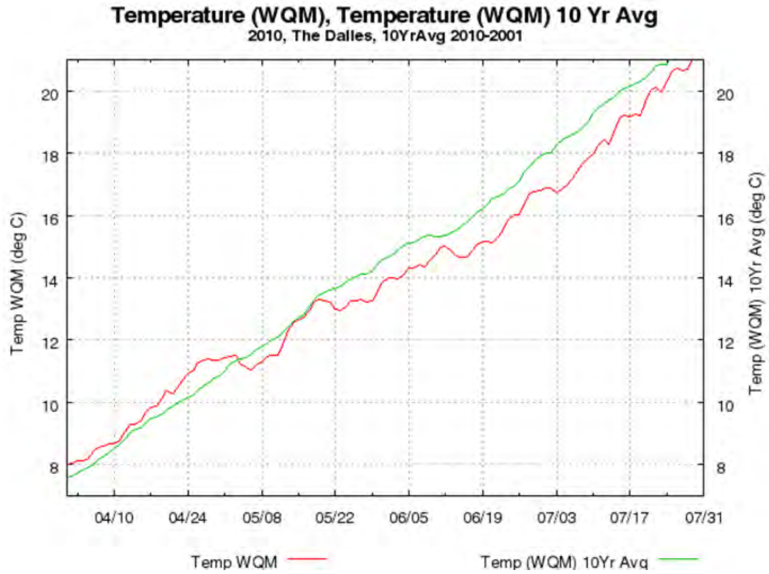


Figure 1.6. Water Temperature from The Dalles Dam Water Quality Monitoring Station. Obtained on June 6, 2011 from http://www.cbr.washington.edu/dart.

During the spring and summer 2010 study periods, forebay elevation averaged 158.4 and 158.9 ft, respectively, referenced to mean sea level (Figure 1.7). The range was 1.3 ft during each season.

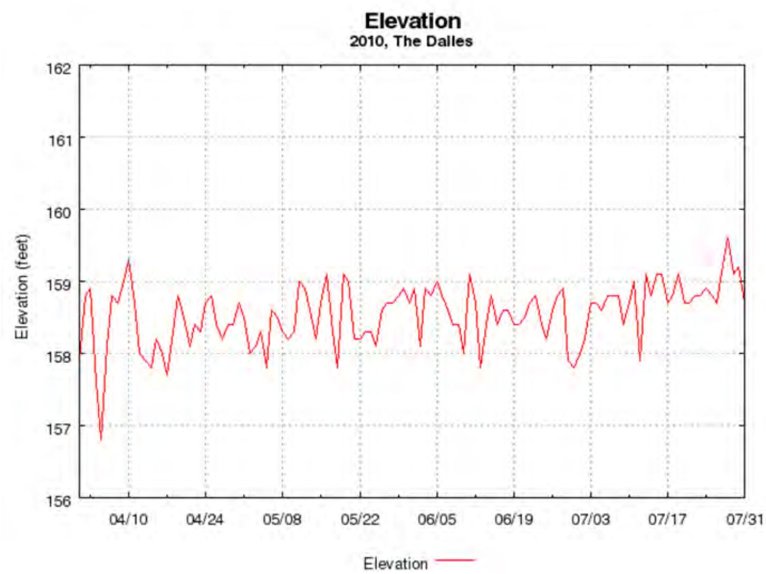


Figure 1.7. Forebay Elevation at The Dalles Dam. Obtained on June 7, 2011 from http://www.cbr.washington.edu/dart.

1.6 Report Contents

This report contains seven chapters and three appendices. After this introduction (Chapter 1.0), we present the methods (Chapter 2.0), followed by the study results for survival, travel time, passage efficiency, and distribution for yearling Chinook salmon (Chapter 3.0), steelhead (Chapter 4.0), and subyearling Chinook salmon (Chapter 5.0). Discussion of study results (Chapter 6.0) and references (Chapter 7.0) close out the main body of the report. In the appendices we provide Juvenile Salmon Acoustic Telemetry System performance data (Appendix A), tagging and release data (Appendix B), hydrophone deployment locations (Appendix C), capture histories (Appendix D), and an assessment of the assumptions for the survival estimates (Appendix E).

2.0 Methods

Study methods cover environmental conditions, the release-recapture design and hydrophone deployment; tag life; fish handling, tagging, and release procedures; acoustic signal processing; and statistical methods. The primary research tool was the Juvenile Salmon Acoustic Telemetry System (JSATS; McMichael et al. 2010). In brief, an acoustic signal emitted by a transmitter implanted in a test fish is received at an underwater hydrophone and sent to a digital signal processor where the unique wave form is detected, then decoded and output is written to a storage device. Filtering involves identifying repeated identical tag codes that arrive at time intervals expected from a normally functioning acoustic tag like those implanted in fish. Performance data for the JSATS equipment is presented in Appendix A.

2.1 Environmental Conditions

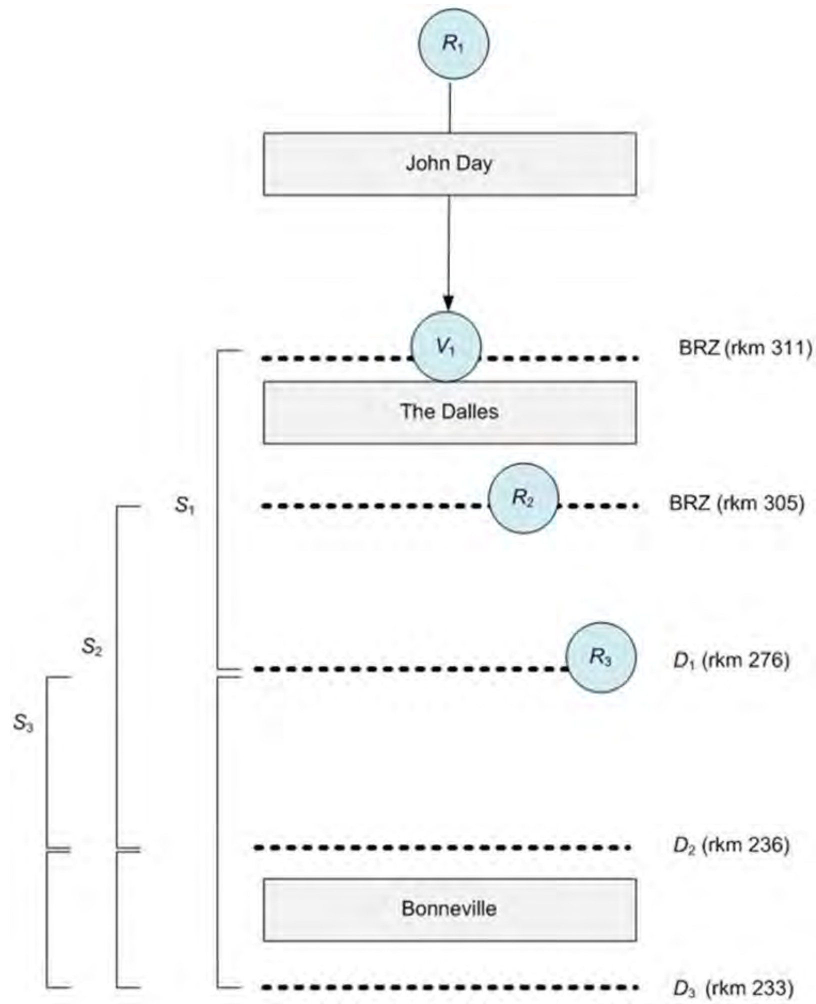
Water discharge data by spill bay and turbine unit and elevation data for the forebay and tailrace are acquired by the USACE in 5-minute increments by the automated data-acquisition system at TDA. Operators at the dam provided the data to us weekly. The 5-minute discharge data for the entire dam and spillway were averaged by day and plotted together with daily averages for the previous 10-year period to provide some historical perspective for 2010 observations. Average water discharge and forebay water temperature data from 1999 through 2009 were downloaded from the UW's Data Access in Real Time website (DART; http://www.cbr.washington.edu/dart).

2.2 Release-Recapture Design and Sample Sizes

The release-recapture design used to estimate dam passage survival at TDA consisted of a combination of a virtual release (V_1) of fish at the face of the dam and a paired release below the dam (Figure 2.1) (Skalski et al. 2010). Tagged fish released above John Day Dam (JDA) were used to supply a source of fish known to have arrived alive at the face of TDA. By releasing the fish far enough upstream, they should have arrived at the dam in a spatial pattern typical of run-of-river (ROR) fish. This virtual-release group was then used to estimate survival through the dam and part of the way through the next reservoir (i.e., rkm 275) (Figure 2.1). To account and adjust for this extra reach mortality, a paired release below TDA (i.e., R_2 and R_3) (Figure 2.1) was used to estimate survival in that segment of the reservoir below the dam. Dam passage survival was then estimated as the quotient of the survival estimates for the virtual release to that of the paired release. The sizes of the releases of the acoustically tagged fish used in the dam passage survival estimates are summarized in Table 2.1.

Table 2.1. Sample Sizes of Acoustic-Tag Releases Used in the Yearling Chinook Salmon and Steelhead Survival Studies at The Dalles Dam in 2010

Release Location	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
Above John Day Dam (R_1)	2,287	2,288	2,849
Virtual Release (V_1)	2,037	2,048	2,417
The Dalles Dam Tailrace (R_2)	796	799	800
Bonneville Reservoir (R_3)	797	798	800
Total Tagged and Released	3,880	3,885	4,449



$$\hat{S}_{\text{Dam}} = \frac{\hat{S}_1 \cdot \hat{S}_2}{\hat{S}_3}$$

Figure 2.1. Schematic of Releases (R) and Detection Locations (Dashed Lines) Used in Estimating Dam Passage Survival at The Dalles Dam in 2010. Note, the BRZ arrays at rkm 311 and rkm 307 are not actually on the BRZ demarcations. The arrays labeled rkm 305 and 276 were actually at rkm 307 and 275, respectively.

In addition to the detection arrays identified in Figure 2.1, hydrophone arrays were deployed below Bonneville Dam (BON) at rkm 153, 113, and 86. These arrays served as potential additional downstream detection arrays to improve precision in the survival analysis for fish passing TDA.

The same release-recapture design was also used to estimate forebay-to-tailrace survival, except that the virtual-release group was constructed of fish known to have arrived at the forebay array. The same below-dam paired release that was used to estimate dam passage survival was used to adjust for the extra release mortality below the dam. The double-detection arrays at the face of the dam (Figure 2.2) were sampled as two independent arrays to allow estimation of detection probabilities by route of passage and assign the location of last detection, i.e., the passage route.

The three-dimensional (3D) double-detection array at the face of TDA used to construct the virtual–release group was also used to identify the passage routes of fish through the dam. These passage-route data were used to calculate SPE and fish passage efficiency (FPE) at TDA. The 3D tracking data were further used to estimate forebay residence time within the 100-m zone nearest the dam. The fish used in the virtual release at the face of the dam were used to estimate tailrace egress time.

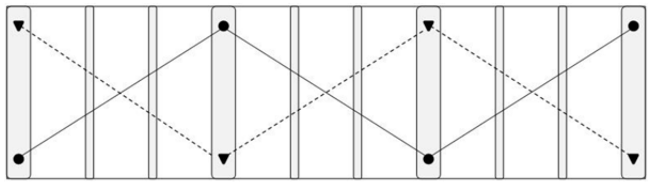


Figure 2.2. Front View Schematic of Hydrophone Deployments at Three Turbines Showing the Double-Detection Arrays. Circles denote the hydrophones of Array 1 and triangles denote the hydrophones of Array 2.

2.3 Tag Specifications and Tag Life

The acoustic tags used in the 2010 study (Figure 2.3) were manufactured by Advanced Telemetry Systems (ATS). Each tag, model number ATS-156dB, measured 12.02 mm in length, 5.21 mm in width, 3.72 mm in thickness, and weighed 0.430 g in air. The tags had a nominal transmission rate of 1 pulse every 3 seconds. Nominal tag life was expected to be about 25 d.

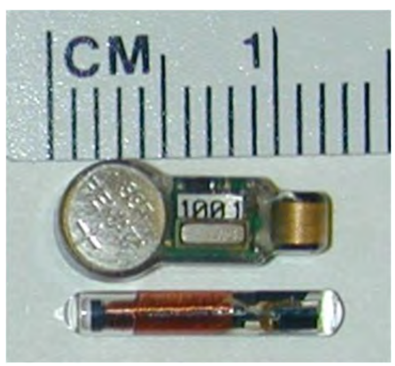


Figure 2.3. JSATS 0.43-g Acoustic Micro-Transmitter and PIT Tag Surgically Implanted in Yearling and Subyearling Chinook Salmon and Steelhead Smolts in 2010

For an assessment of tag life, 49 and 50 acoustic tags were randomly sampled from the tags used in the spring and summer seasons, respectively. The tags were activated, held in river water, and monitored continuously until they failed. All acoustic tags were enclosed in water-filled plastic bags and suspended from a rotating foam ring within a 2-m-diameter fiberglass tank. Two 90° × 180° hydrophones were positioned 90° apart in the bottom of the tank and angled upward at approximately 60° to maximize coverage for detecting acoustic signals. Hydrophones were cabled to a quad-channel receiver that amplified all acoustic signals. All acoustic signals were then saved, decoded, and processed. Post-processing software calculated the number of hourly decodes for each acoustic tag, and therefore tag failure times could be determined within ±1 h. The tag failure times were fit to the four-parameter vitality model of Li and Anderson (2009). The vitality model tends to fit acoustic-tag failure times well, because it allows for both early onset of random failure due to manufacturing as well as systematic battery failure later on. The probability density function for the vitality model can be rewritten as

$$f(t) = 1 - \left(\Phi\left(\frac{1 - rt}{\sqrt{u^2 + s^2 t}} \right) - e^{\left(\frac{2u^2 r^2}{s^4} + \frac{2r}{s^2} \right)} \Phi\left(\frac{2u^2 r + rt + 1}{\sqrt{u^2 + s^2 t}} \right) \right)^{e^{-kt}} \tag{2.1}$$

where: Φ = cumulative normal distribution,
r = average wear rate of components,
s = standard deviation in wear rate,
k = rate of accidental failure,
u = standard deviation in quality of original components.

The random failure component, in addition to battery discharge, gives the vitality model additional latitude to fit tag-life data not found in other failure-time distributions such as the Weibull or Gompertz. Parameter estimation was based on maximum likelihood estimation. For the virtual-release group (V_1) based on fish known to have arrived at the dam and with active tags, the conditional probability of tag activation, given the tag was active at the detection array at rkm 309 (TDA dam face), was used in the tag-life adjustment for that release group. The conditional probability of tag activation at time t_1, given it was active at time t_0, was computed by the quotient

$$P(t_1 | t_0) = \frac{S(t_1)}{S(t_0)}.$$

2.4 Handling, Tagging, and Release Procedures

Fish obtained from the JDA juvenile bypass system (JBS) were surgically implanted with JSATS tags, and then transported to three different release points, as described in the following sections. A total of 3,880 yearling Chinook salmon, 3,885 steelhead, and 4,449 subyearling Chinook salmon were tagged and released. Tagging and release data are presented in Appendix B.

2.4.1 Fish Source and Collection Methods

The juvenile Chinook salmon and steelhead used in the study were obtained from the Smolt Monitoring Facility (SMF) at JDA. The Pacific States Marine Fisheries Commission diverted fish from the JBS into an examination trough, as described by Martinson et al. (2006). The SMF is situated on the south side of JDA at the downriver edge of the fish bypass system where bypassed juvenile salmonids and other fishes are routed through a series of flumes and dewatering structures. Smolts can be diverted into the SMF as part of a sample of the JBS population for routine smolt monitoring or directed into the tailrace through an outfall pipe located downstream of the facility. Routinely sampled smolts also were rerouted to the tailrace outfall after they were examined unless they were selected for tagging as part of this study of survival rates.

Juvenile salmonids were diverted from the bypass system and routed into a 1,795-gal holding tank in the SMF. About 150 to 200 smolts and other fishes were crowded with a panel net into a 51.2- by

6.14- cm pre-anesthetic chamber. Water levels in the chamber were lowered to about 20.5 cm at which point fish were anesthetized with 60 ml of a stock tricaine methanesulfonate (MS-222) solution prepared at a concentration of 50 g/L. Once anesthetized, fish were routed into the examination trough. Technicians added MS-222 as needed to maintain sedation, and 5 to 10 ml of PolyAqua™ was added to reduce fish stress. Water temperatures were monitored in the main holding tank and in the examination trough, and water in the trough was refreshed before temperatures there increased more than 2°C above those observed in the main holding tank.

Fish ≥95 mm in length without malformations or excessive descaling (>20%) were selected for tagging. Specifically, once in the examination trough, smolts targeted for surgical procedures were evaluated in accordance with the following specific acceptance and rejection criteria:

- Qualifying (Acceptable) Conditions
  - length ≥95 mm
  - visible elastomer tag(s) present or absent
  - adipose-fin clipped or unclipped
  - short operculum
  - healed (moderate) injuries (e.g., bird strikes)
  - ≤3% fungal patch
  - minor fin blood
  - partial descaling (3–19%)
  - steelhead with eroded pectoral or ventral fins (likely hatchery steelhead).
- Disqualifying Conditions
  - <95 mm long
  - ≥20% descaling
  - obvious signs of bacterial kidney disease (BKD)
  - popeye
  - >3% coverage with fungus
  - skeletal deformation
  - head deformation
  - lesions
  - moribund
  - emaciation
  - lacerations
  - hemorrhage
  - PIT- or radio-tagged or other post-surgical fishes

– notable operculum damage (except short operculum)
– fin rot
– parasites.

Nontarget species and fish that did not meet the above criteria were released to the river through the SMF holding system after a 30-minute recovery period. Accepted fish were counted and released into transfer buckets containing fresh river water before being moved to one of six 80-gal pre-surgery holding tanks, where they were held for 18 to 30 h before surgery. The pre-surgery holding duration depended on the time of collection and the time of tagging on the next day.

During spring and summer tagging seasons, 1,957 out of 12,214 fish were rejected for tagging (16%). Fish that were rejected during the tagging process were placed in a recovery tank to allow for the anesthesia to be displaced from their system before releasing them. The total number of fish rejected and reason for their rejection are listed in Table 2.2.

Table 2.2. Number of Fish Rejected by Criteria During Spring and Summer Tagging at John Day Dam (CH1=Yearling Chinook, SH=Steelhead, CH0=Subyearling Chinook)

Rejection Criteria	Number Rejected CH1	Number Rejected STH	Number Rejected CH0
Descaling	147	208	227
Fungus	48	60	9
Bacterial kidney disease	2	0	2
Skeletal deformation	8	6	10
Parasites	0	4	34
Emaciation	1	0	1
Lacerations	30	47	71
Hemorrhage	12	2	5
Popeye	12	6	5
Fin Rot	5	1	5
Head deformation	1	1	1
Lesions	14	21	23
Moribund	0	0	2
Operculum damage	16	42	25
Size	11	151	203
PIT tagged	156	149	119
Other	16	33	5

2.4.2 Tagging Procedure

The team followed the latest guidelines for surgical implantation of acoustic transmitters in juvenile salmonids (Brown et al. 2010). Procedure development is an ongoing process initiated by the USACE for contractors conducting survival studies. Numerous steps were taken to minimize the handling impacts of collection and surgical procedures. Most smolts used for tagging were part of the routine collection for SMF monitoring and additional fish did not have to be collected to meet the tagging quota on most days.

Fish were netted in small groups from the 80-gal holding tanks and placed in a 5-gal "knockdown" bucket with water and 20 mL of a 40-g/L stock solution of MS-222. Once a fish lost equilibrium, it was transferred to a processing table in a small container of river water. Species type, whether the adipose fin was intact or clipped, and fork length (±1 mm) were recorded on a GTCO CalComp Drawing Board VI digitizer board. Fish were weighed (±0.01 g) on an Ohaus Navigator scale and returned to the small transfer container along with an assigned PIT tag and an activated acoustic tag. Length, weight, species type, tag codes, and fin clip were all added automatically to the tagging database by PIT Tag Information System (PTAGIS) P3 software to minimize human error. The transfer container, fish, and tags were assigned a recovery bucket number and passed to the photo table. Photographs were taken of both sides of the fish while they were in the transfer container, and then the fish were given to a surgeon for tag implantation.

An established protocol was used in the tagging process to help minimize the handling impact on tagged fish. All surgical instruments were sterilized daily in an autoclave and each surgeon used four complete sets of instruments during each day's tagging. When a set was not being used, it was placed in a 70% ethanol solution for approximately 10 minutes. The instruments were then transferred to a distilled water bath for 10 minutes, to remove residual ethanol and any remaining particles, before being used again. To reduce the disruption of the mucus membrane at the incision, Poly-Aqua™ was used to help replace the membrane that was removed from the fish's epidermal layers. Anesthesia buckets were kept within ±1°C of river water temperature. Anesthesia solutions were either replaced or cooled with ice when temperatures exceeded protocols. Recovery buckets were also kept within ±1°C of river water temperature.

The fish to be tagged were anesthetized in an 18.9-L "knockdown" bucket with fresh river water and MS-222 (tricaine methanesulfonate; 80 mg/L). Anesthesia buckets were refreshed repeatedly to maintain the temperature within ± 1°C of current river temperatures. Each fish was weighed and measured before tagging. During surgery (Figure 2.4), each fish was placed ventral side up and a gravity-fed anesthesia supply line was placed into its mouth. The dilution of the "maintenance" anesthesia was 40 mg/L. Using a surgical blade, a 6- to 8-mm incision was made in the body cavity between the pelvic girdle and pectoral fin. A PIT tag was inserted followed by an acoustic tag. Both tags were inserted toward the anterior end of the fish. The incision was closed using 5-0 Monocryl suture. Two interrupted sutures of 5-0 monofilament with an RB-1 needle were used to close the incision. After closing the incision, the fish were placed in a dark 18.9-L transport bucket filled with aerated river water. Fish were held in these buckets for 18 to 24 h before being transported for release into the river. The loading rate was five fish per bucket.

The number of personnel on hand was the biggest contributor to ensuring that all tagged fish were handled as efficiently and un-intrusively as possible to minimize handling times. A team of eight or nine people conducted the tagging process. One individual was responsible for anesthetizing fish and delivering them to be weighed and measured; two people were responsible for weighing, measuring, and recording data; one person was responsible for taking lateral photographs with a high-resolution digital camera; three people performed surgeries to implant tags in the fish; and one or two people were responsible for moving tagged fish in transport buckets to post-surgery tanks.

Figure 2.4. Surgical Implantation of Tags

2.4.3 Recovery and Holding

Tagged fish were placed in 5-gal aerated transport buckets and closely monitored until fish had reestablished equilibrium. Each bucket held one to five fish depending on the size of the fish and the number to be released at each site. The buckets were then carried to a larger holding tank where they were supplied with a continuous feed of river water (Figure 2.5). Fish were held and monitored for 18 to 30 h prior to being released. The large holding tanks were insulated to keep the water temperature within acceptable limits.

Figure 2.5. Post-Surgery Holding Tank with Recovery Buckets

2.4.4 Fish Transportation and Release

Tagged fish were transported from JDA by truck to the three release locations (Figure 2.1). To transport tagged fish, two ¾-ton trucks were outfitted with two 180-gal Bonar insulated totes. The totes could hold ten 5-gal fish buckets. The totes had snug-fitting lids and some extra space inside so that ice could be added for cooling on hot days. A network of valves and plastic tubing was attached to an oxygen tank for delivering oxygen to the totes from a 2200-psi oxygen tank during transport. The Bonar totes were filled with fresh river water before fish buckets were removed from the post-surgery holding tanks and placed in the totes. Air lines were then placed into the totes. A YSI meter was used to measure the dissolved oxygen and the temperature of water in the totes before and after transport to make sure that these properties stayed within acceptable limits. Transportation routes were adjusted to provide equal travel times to each release location from JDA.

Upon arriving at a release site, fish buckets were transferred to a boat for transport to the in-river release location. There were five release locations at each release cross section. Equal numbers of buckets of fish were released at each of the five locations for a given cross section. During spring, releases occurred for 37 consecutive days (from April 28 to June 1, 2010). During summer, releases occurred for 35 consecutive days (from June 13 to July 17, 2010). Releases alternated between daytime and nighttime, every other day, over the course of the study. The timing of the releases at the three locations was staggered to help facilitate downstream mixing (Table 2.3).

Just before fish were released in the river, fish buckets were opened to check for dead fish. Every dead fish was scanned with a BioMark portable transceiver PIT-tag scanner to identify the implanted PIT-tag code. The associated acoustic-tag code was identified later from tagging data that recorded all pairs of PIT and acoustic tags implanted in fish the previous day. Dead fish were released once a week to determine whether they were detected on downstream survival-detection arrays. Post-tagging, pre-release mortalities were low for each run of fish studied in 2010 (YC = 0.23%; STH = 0.18%; SYC = 0.29%).

Table 2.3. Relative Release Times for the Acoustically Tagged Fish to Accommodate Downstream Mixing. Releases were timed to accommodate the approximately 60-h travel time between R1 and R2 and the 13-h travel time between R2 and R3.

	Relative Release Times	
Release Location	Daytime Start	Nighttime Start
R_1 (rkm 390)	Day 1: 0900 h	Day 2: 2000 h
R_2 (rkm 307)	Day 3: 2000 h	Day 5: 0900 h
R_3 (rkm 275)	Day 4: 0900 h	Day 5: 2200 h

2.5 Detection of Tagged Fish

Two types of JSATS arrays, cabled and autonomous, were deployed to detect fish tagged with JSATS acoustic transmitters as they passed downstream through the study reach between Roosevelt, Washington, at rkm 390, and Oak Point, Washington, at rkm 86.2 (Table 2.4). The Dalles Dam forebay array was the primary array for creating virtual releases for estimating the survival rate for tagged smolts passing from the forebay entrance to the tailrace. The dam-face array was used to regroup fish to form virtual releases for estimating TDA dam-passage survival. The Hood River, Oregon, array was used as the primary survival-detection array for virtual of fish passing TDA. The Bonneville (BONDam-face array was used as the secondary survival-detection array for estimating the survival of virtual releases of fish passing TDA and as the primary survival detection array for estimating survival of the tailrace and tailwater reference release groups. The first BON tailwater array near Vancouver, Washington, was used as a tertiary survival-detection array for estimating the product of survival and detection probabilities for estimating TDA passage survival rate. Hydrophone deployment locations are listed in Appendix C.

Table 2.4. Description, Location, Name, and Survival Model Function of Arrays Deployed in 2010. Array names were a concatenation of "A" for autonomous or "D" for dam face with a sequential number for each type (from upstream to downstream) with "CR" for Columbia River, and the nearest whole rkm.

Array Description	Location	Array Name	Array Function
TDA Forebay	2 km upstream TDA	A3CR311	Forebay-to-tailrace survival; forebay residence time
TDA Dam Face	The Dalles Dam	D2CR309	Regroup fish for route-specific virtual releases
TDA Tailwater	2 km downstream	A4CR307	Detect tagged fish to estimate egress rate and project passage time
Hood River	near Hood River, OR	A5CR275	TDA primary for virtual releases of fish (at the forebay entrance or dam face)
BON Dam Face	Bonneville Dam	D2CR234	TDA secondary for virtual releases and primary for TDA tailrace and tailwater reference releases of fish
Below BON 1	near Vancouver, WA	A8CR153	TDA tertiary for virtual releases at TDA; TDA secondary array for TDA reference release groups.
Below BON 2	near Kalama, WA	A9CR113	Primary for estimating CR153 to CR113 survival
Below BON 3	near Oak Point, WA	A10CR086	Primary for estimating CR113 to CR086 survival
Below BON 4	Pooled locations		CR049.6 to River mouth to estimate product of survival and capture rates for the final river segment CR086 to CR049.6.

2.5.1 Cabled Dam-Face Arrays

The cabled dam-face receiver was designed by PNNL for the USACE using an off-the-shelf user-build system (Weiland et al. 2011). Each cabled receiver consists of a computer, data-acquisition software, digital signal-processing cards with field-programmable gate array (DSP+FPGA), global positioning system (GPS) card, four-channel signal-conditioning receiver with gain control, hydrophones, and cables (Figure 2.6). The software that controls data acquisition and signal processing is the property of the USACE and is made available by the USACE as needed. All cabled receivers were tested for performance in an anechoic tank prior to deployment (Deng et al. 2010).

A modular JSATS cabled array was deployed along the upstream face of TDA to detect JSATS-tagged smolts approaching the dam. Two hydrophones were deployed at different depths on each main pier and six hydrophones attached to clump mounts were lowered to the bottom of the forebay about 33 m upstream of the dam face (Figure 2.7). Clump-mounted hydrophones were deployed to provide additional detections off of the plane of the dam face to increase the resolution of 3D tracking.

The dam-face cabled array consisted of 25 cabled receivers, each supporting up to 4 hydrophones. A total of 50 hydrophones were deployed on powerhouse piers and associated receivers were housed in trailers on the forebay deck. Hydrophones were deployed on trolleys in pipes attached to the main piers at the powerhouse and spillway (Figure 2.7) in a known fixed geometry. Trolley pipes at the powerhouse were 4 in. in diameter, and made of powder-coated, schedule 40 steel that was slotted down one side for deployment of the trolley. A cone was attached to the top of the pipe to assist with trolley insertion (Figure 2.8). Pipes at the powerhouse were 80 ft long and extended from deck level at elevation 185 ft above MSL down to a mid-intake depth at elevation 105 above MSL. One hydrophone on each pier was deployed at a shallow elevation (147 ft above MSL) and another was deployed at a deep elevation (107 ft above MSL) to provide acceptable geometries for tracking an acoustically tagged fish in three dimensions and then assigning it a route of passage through the dam.

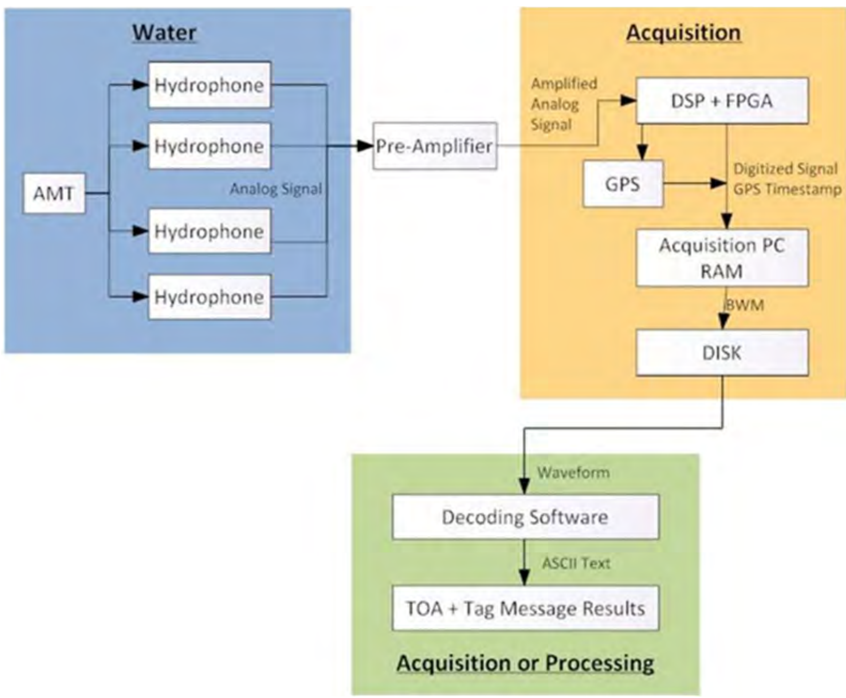


Figure 2.6. Schematic of Dam-Face Receiver System Showing the Main Components and Direction of Signal Acquisition and Processing. Abbreviations are as follows: AMT = acoustic micro-transmitter implanted in fish; DSP = digital signal processing card; FPGA = field programmable gate array; GPS = global positioning system; PC = personal computer; RAM = random access memory; BWM = binary waveform; TOA = time of arrival.

Six clump mounts were also deployed in the forebay, two on each end of the powerhouse and in front of the sluiceways, and two in the spillway forebay. The location of clump mounts was estimated from detection of transmitted codes from a beacon on each clump mount by multiple hydrophones at known locations on the dam face. Each clump mount had a single hydrophone for detecting tags implanted in approaching fish or beacons mounted on adjacent clump mounts or select dam-face hydrophones.

Figure 2.7. Location of Hydrophones on the Dam Face and in the Forebay of The Dalles Dam, 2010. The green and red symbols represent dam-face and clump mount hydrophones, respectively.

Figure 2.8. Trolley Pipe Mounted on a Main Pier of The Dalles Dam Powerhouse

At the spillway, hydrophones were mounted on trolleys that were deployed in 60-ft-long 4-in.-diameter slotted pipes. At each spillway pier, one hydrophone was deployed at a shallow elevation (151 ft above MSL) and the other at a deep elevation (123 ft above MSL). A total of 30 hydrophones were deployed on spillway piers. Each steel trolley slid down inside the pipe and was guided by an extension arm that protruded from the slot. The arm positioned the anechoic baffled hydrophone perpendicular to the face of the dam (Figure 2.9).

Figure 2.9. Trolleys Used to Deploy Hydrophones at The Dalles Dam Powerhouse and Spillway, 2010. A 4-in.-diameter trolley with hydrophone for deploying in slotted pipes on powerhouse and spillway piers. Each trolley had a steel arm to support a hydrophone that was surrounded by a plastic cone lined with anechoic material to prevent sound reception from a downstream direction.

2.5.2 Autonomous Receiver Arrays

Autonomous acoustic telemetry receivers were deployed in arrays at specific sites in the lower Columbia River study. An array is defined as a group of autonomous nodes deployed across the entire width of a river cross section to detect passing fish that had been surgically implanted with acoustic tags. Most arrays had autonomous nodes that were deployed within 400 ft of each other and less than 250 ft from shore. The hydrophone, pair of electronic circuit boards, compact flash (CF) card, and battery connectors were located in the node top (Figure 2.10).

Figure 2.10. Side (Left) and Bottom (Right) Views of an Autonomous Node Top

Eight arrays of autonomous nodes were deployed for this study (Figure 2.11). Arrays were named by concatenating several letters and numbers. For example, the first array was A1CR351, which is the concatenation of "A" (for autonomous node), a sequential array number (counting from upstream to downstream), "CR" (for Columbia River), and 351, which is the nearest river kilometer to that array site. This array was located 2 km upstream of JDA. A tailwater egress array (A2CR346) was located at rkm 346 about 2 km downstream of the tailrace deck of JDA. The Dalles Dam forebay entrance array (A3CR311) was located 2 km upstream of TDA spillway. A tailwater egress array (A4CR307) was located about 2 km downstream of the tailrace deck of TDA. A fifth array (A5CR275) was located at the third release site, R_3, near Hood River, Oregon. The BON forebay array (A6CR236) was located about 2 km upstream of the second powerhouse at BON. A tailwater egress array (A7CR233) was located about 1 km downstream of BON. The tertiary array for estimating the product of detection and survival rates for TDA (A8CR153) was located near Vancouver, Washington, in the BON tailwater. The secondary array (A9CR113) for estimating the product of detection and survival for the BON passage survival estimate was deployed near Kalama, Washington. A tertiary array (A10CR086) for BON was deployed at rkm 86 near Oak Point, Washington.

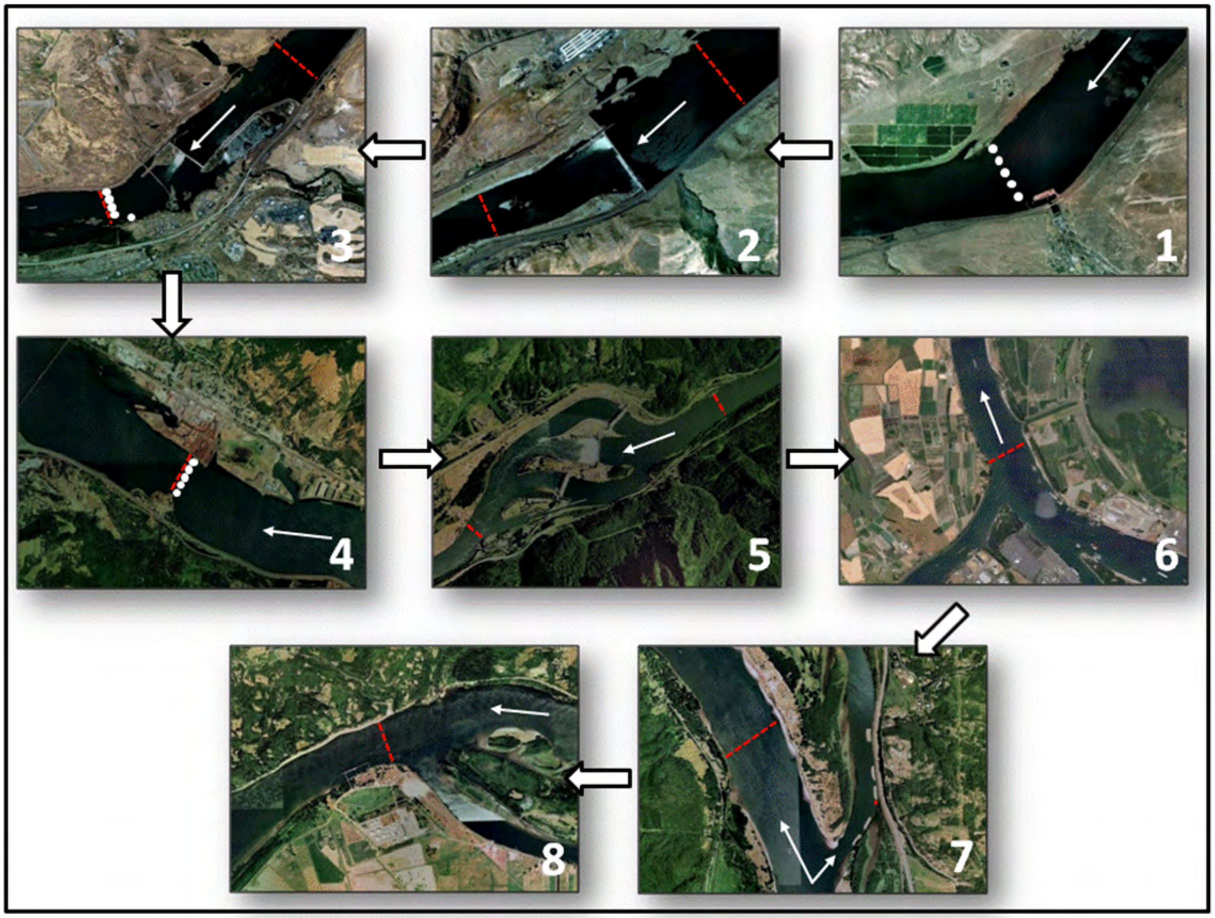


Figure 2.11. Location of the Three Fish-Release Transects (White Circles in Images 1, 3, and 4) for the 2010 Study and Locations of Autonomous Nodes (Red Dashed Lines) Deployed in Arrays to Detect Acoustically Tagged Fish Migrating Downstream. Black arrows between Google Earth images indicate the order of images from upstream to downstream, and the direction of water flow within each image is indicated by white arrows. Image 1: fish release location, R1, near Roosevelt, Washington, at rkm 390; image 2: John Day Forebay Array (right; A1CR351) and Tailrace Array (left; A2CR346); image 3: The Dalles Forebay Array (right; A3CR311), Tailrace Array (left; A4CR307) and fish release location R2; image 4: fish release location R3 and associated array (A5CR275); image 5: Bonneville Forebay Array (right; A6CR236) and Tailrace Array (left; A7CR233); image 6: Bonneville Tailwater Array near Vancouver, WA (A8CR153); image 7: Bonneville Tailwater Array near Kalama, Washington (A9CR113); and image 8: Bonneville Tailwater Array near Oak Point, WA (A10CR086). Array names are presented in parentheses, and the three-digit number at the end of each name is the river kilometer upstream from the mouth of the Columbia River.

We usually retrieved nodes by boat once every 2 weeks to download data, and batteries were replaced once every 28 days. The first step in servicing a node was to trigger its acoustic release. Staff entered a release-specific code into a topside command transceiver, and it transmitted an electrical signal to an underwater transducer, which in turn converted the electrical signal into underwater sound detectable by an acoustic modem on the upper end of the acoustic release mechanism. Upon receipt of a coded sound, the release mechanism usually would open and free the positively buoyant package from the anchor so that it would surface and could be retrieved by staff in the boat. The next step was to dry the node with a towel, open it, eject the CF card, and download the data from the card to a laptop computer. Each file was checked to verify that data were collected during the entire deployment, records were continuous, and records included time stamps and tag detections. The CF card was replaced every time nodes were retrieved. If data were corrupt, the node top was replaced with a new one and the faulty top was sent to Sonic Concepts for repair. Damage to the relatively delicate hydrophone tip was the most common problem. Nodes were deployed and serviced from April 26 until August 4, 2010.

Autonomous nodes were rigged with the configuration shown in Figure 2.12. A 5-ft section of rope with three 6-lb buoyancy floats was attached to a strap half way between the node tip and the bottom of the battery housing. An acoustic release (InterOcean Systems Model 111 [A6CR236]) was attached to the other end of the 5-ft line. A 1-, 3-, or 6-ft length of wire rope was attached to the bottom of the acoustic release, depending on water depth, and the other end of that cable was shackled to a 75-lb steel anchor. The shorter 1-ft length of wire rope was used in water less than 40 ft deep; the 3-ft length was used in water over 40 ft deep; and 6-ft lengths were used in deep locations where sandy substrates had the potential to gum up release mechanisms.

2.6 Acoustic Signal Processing and Analysis

Data collected by the JSATS cabled hydrophones were encoded candidate messages saved in binary time-domain waveform files. Figure 2.13 shows the waveforms of an actual example acquired at the JDA spillway on June 18, 2008. The waveform files were then processed by a decoding utility (Waveform Utilities developed by the USACE and PNNL) that identifies valid tag signals and computes the tag code and time of arrival using Binary Phase Shift keying. Binary Phase Shift keying is a digital-modulation technique that transmits messages by altering the phase of the carrier wave. Several filtering algorithms were then applied to the raw results from the decoding utilities to exclude spurious data and false positives.

Transmissions of JSATS tag codes received on cabled and autonomous hydrophones were recorded in raw data files. These files were downloaded periodically and transported to PNNL's North Bonneville offices for processing. Tag-detection data from JSATS autonomous nodes were processed by two independent groups as a quality-control measure as in previous studies (Ploskey et al. 2007, 2008) using standardized methods. Receptions of tag codes within raw data files were processed to produce a data set of accepted tag-detection events. For cabled arrays, detections from all hydrophones at a dam were combined for processing. The following three filters were used for data from cabled arrays:

- Multipath filter: For data from each individual cabled hydrophone, all tag-code receptions that occur within 0.156 seconds after an initial identical tag code reception were deleted under the assumption that closely lagging signals are multipath. Initial code receptions were retained. The delay of 0.156 seconds was the maximum acceptance window width for evaluating a pulse repetition interval (PRI) and was computed as 2(PRI_Window+12×PRI_Increment). Both PRI_Window and

PRI_Increment were set at 0.006, which was chosen to be slightly larger than the potential rounding error in estimating PRI to two decimal places.

- Multi-detection filter: Receptions were retained only if the same tag code was received at another hydrophone in the same array within 0.3 seconds because receptions on separate hydrophones within 0.3 seconds (about 450 m of range) were likely from a single tag transmission.
- PRI filter. Only those series of receptions of a tag code (or "messages") that were consistent with the pattern of transmissions from a properly functioning JSATS acoustic tag were retained. Filtering rules were evaluated for each tag code individually, and it was assumed that only a single tag would be transmitting that code at any given time. For the cabled system, the PRI filter operated on a message, which included all receptions of the same transmission on multiple hydrophones within 0.3 seconds. Message time was defined as the earliest reception time across all hydrophones for that message. Detection required that at least six messages were received with an appropriate time interval between the leading edges of successive messages.

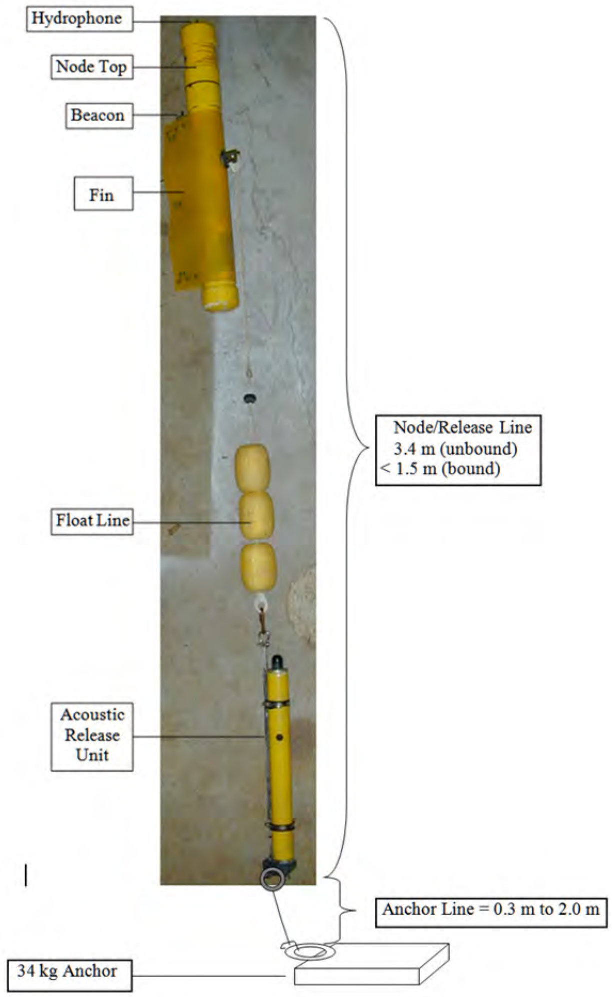


Figure 2.12. Autonomous Node Rigging

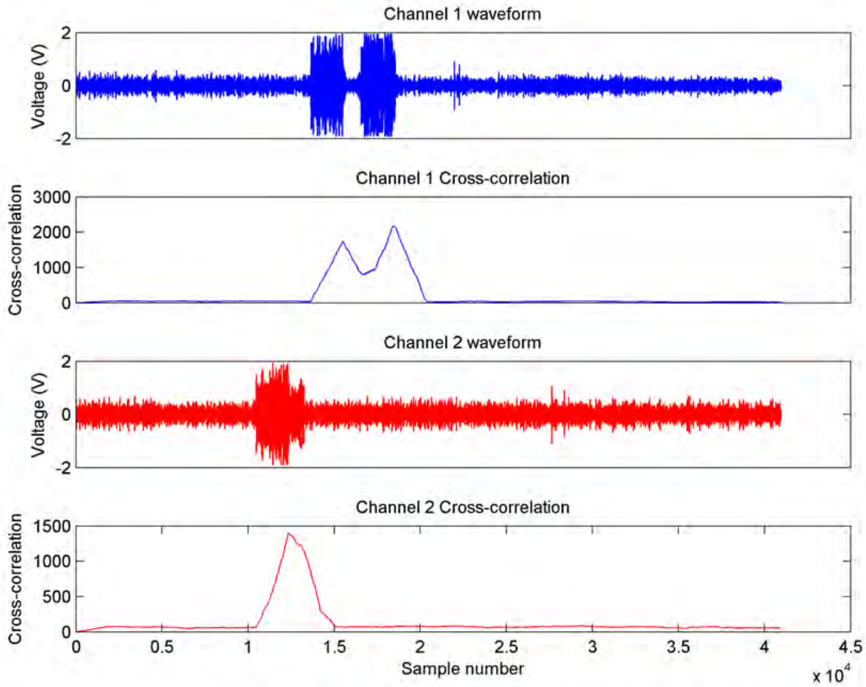


Figure 2.13. Example of Time-Domain Waveforms and Corresponding Cross-Correlations Acquired at the John Day Dam Spillway. The message portion was 1,860 samples (744 µs long). Note that multipath components were present in both channels. Decodes from the multipath components were filtered out in post-processing.

Like the cabled-array data, receptions of JSATS tag codes within raw autonomous node data files are processed to produce a data set of accepted tag detection events. A single file is processed at a time, and no information on receptions at other nodes is used. The following two filters are used during processing of autonomous node data:

- Multipath filter: Same as for the cabled-array data.
- PRI filter: Only those series of receptions of a tag code (or "hits") that were consistent with the pattern of transmissions from a properly functioning JSATS acoustic tag were retained. Each tag code was processed individually, and it was assumed that only a single tag will be transmitting that code at any given time.

The output of the filtering processes for both cabled and autonomous hydrophones was a data set of events that summarized accepted tag detections for all times and locations where hydrophones were operating. Each unique event record included a basic set of fields that indicated the unique identification number of the fish, the first and last detection time for the event, the location of detection, and how many messages were detected within the event. This list was combined with accepted tag detections from the autonomous arrays and PIT-tag detections for additional quality assurance/quality control analysis prior to survival analysis. Additional fields capture specialized information, where available. One such example was route of passage, which was assigned a value for those events that immediately precede passage at a dam based on spatial tracking of tagged fish movements to a location of last detection. Multiple receptions of messages within an event can be used to triangulate successive tag position relative to hydrophone locations.

One of the most important quality control steps was to examine the chronology of detections of every tagged fish on all arrays above and below the dam-face array to identify any detection sequences that deviate from the expected upstream to downstream progression through arrays in the river. Except for possible detections on forebay entrance arrays after detection on a nearby dam-face array 1 to 3 km downstream, apparent upstream movements of tagged fish between arrays that were greater than 5 km apart or separated by one or more dams were very rare (<0.015%) and probably represented false positive detections on the upstream array. False positive detections usually will have close to the minimum number of messages and were deleted from the event data set before survival analysis.

Three-dimensional tracking of JSATS-tagged fish in the immediate forebay of TDA was used to determine routes of passage to estimate passage efficiencies and horizontal distribution of passage, as well as forebay approach and forebay vertical distributions (Deng et al. 2011). Acoustic tracking is a common technique in bioacoustics based on time-of-arrival differences among different hydrophones. Usually, the process requires a three-hydrophone array for 2D tracking and a four-hydrophone array for 3D tracking. For this study, only 3D tracking was performed. The methods were similar to those described by Weiland et al. (2010) for JDA.

2.7 Statistical Methods

The statistical methods include tests of assumptions and estimation of dam passage survival, forebay-to-tailrace survival, travels times, passage efficiencies, and distributions. Capture histories and assessments of the survival model assumptions are contained in Appendices D and E, respectively.

2.7.1 Tests of Assumptions

2.7.1.1 Burnham et al. (1987) Tests

Tests 2 and 3 of Burnham et al. (1987) have been used to assess whether upstream detection history has an effect on downstream survival. Such tests are most appropriate when fish are physically recaptured or segregated during capture as in the case of PIT-tagged fish going through the JBS. However, acoustic-tag studies do not use physical recaptures to detect fish. Consequently, there is little or no relevance of these tests in acoustic-tag studies. Furthermore, the very high detection probabilities present in acoustic-tag studies frequently preclude calculation of these tests. For these reasons, these tests were not performed.

2.7.1.2 Tests of Mixing

Evaluation of homogeneous arrival of release groups at downriver detection sites was based on graphs of arrival distributions. The graphs were used to identify any systematic and meaningful departures from mixing. Ideally, the arrival distributions should overlap one another with similarly timed modes.

2.7.1.3 Tagger Effects

Subtle differences in handling and tagging techniques can have an effect on the survival of acoustically tagged smolts used in the estimation of dam passage survival. For this reason, tagger effects were evaluated. The single release-recapture model was used to estimate reach survivals for fish tagged by different individuals. The analysis evaluated whether any consistent pattern of reduced reach survivals existed for fish tagged by any of the tagging staff.

For k independent reach survival estimates, a test of equal survival was performed using the F-test

$$F_{k-1,\infty} = \frac{s_{\hat{S}}^2}{\left(\frac{\sum_{i=1}^{k} \text{Var}\left(\hat{S}_i \middle| S_i\right)}{k} \right)}$$

where

$$s_{\hat{S}}^2 = \frac{\sum_{i=1}^{k} \left(\hat{S}_i - \hat{\bar{S}}\right)^2}{k-1}$$

and

$$\hat{\bar{S}} = \frac{\sum_{i=1}^{k} \hat{S}_i}{k} .$$

The F-test was used in evaluating tagger effects.

2.7.2 Estimation of Dam Passage and Route-Specific Survivals

Maximum likelihood estimation was used to estimate dam passage survival at TDA. The capture histories from all of the replicate releases, both daytime and nighttime, were pooled for the analysis to produce a single season-wide estimate of survival. A joint likelihood model was used to estimate dam passage survival based on the virtual and paired releases corrected for tag life.

The estimate of dam passage survival was computed as a function of three independent reach survival estimates (Figure 2.1) corrected for the probabilities the acoustic tags were still active, i.e.,

$$\hat{S}_{\text{Dam}} = \frac{\left(\frac{\hat{S}_1}{\hat{L}_1}\right)}{\left(\frac{\left(\frac{\hat{S}_2}{\hat{L}_2}\right)}{\left(\frac{\hat{S}_3}{\hat{L}_3}\right)}\right)} = \left(\frac{\hat{S}_1 \hat{S}_3}{\hat{S}_2}\right) \cdot \left(\frac{\hat{L}_2}{\hat{L}_1 \hat{L}_3}\right) \tag{2.1}$$

where $\hat{L}_i$ = estimated probability an acoustic tag is still active associated with reach survival estimate $\hat{S}_i$.

The joint likelihood used to model the three release groups was fully parameterized. Each release was allowed to have unique survival and detection parameters. The fully parameterized model was chosen for purposes of robustness despite empirical evidence that downstream survival and detection probabilities were likely homogeneous. The variance estimate for $\hat{S}_{\text{Dam}}$ takes into account both the release-recapture sampling error and the error in the tag-life estimates according to Townsend et al. (2006). All calculations were performed using Program ATLAS (http://www.cbr.washington.edu/paramest/atlas/) and cross-verified using R and/or Program USER (http://www.cbr.washington.edu/paramest/user/). Analogous estimates were produced for TDA route-specific survivals.

2.7.3 Estimation of Forebay-to-Tailrace Survival

The same virtual/paired-release methods used to estimate dam passage were also used to estimate forebay-to-tailrace survival. The only distinction was the virtual-release group (V_1) was composed of fish known to have arrived alive at the forebay array (rkm 311) of TDA instead of at the dam face (Figure 2.1).

2.7.4 Estimation of Travel Times

Travel times associated with forebay residence and tailrace egress were estimated using arithmetic averages, i.e.,

$$\bar{t} = \frac{\sum_{i=1}^{n} t_i}{n},$$

with the variance of $\bar{t}$ estimated by

$$\widehat{\text{Var}}(\bar{t}) = \frac{\sum_{i=1}^{n} \left(t_i - \bar{t}\right)^2}{n(n-1)},$$

and where t_i was the travel time of the i^{th} fish $(i = 1, \ldots, n)$.

The estimated tailrace egress time was based on the time from last detection of a fish at the double array at the dam face at TDA to the first detector at the tailrace array 2 km downstream of the dam. The estimated forebay residence times were based on the time from the first detection within 100 m of the dam face to the last detection at the double array in front of TDA. In summary,

- Forebay residence time was calculated by subtracting the time of last detection on the dam-face array from the time of first detection on the forebay entrance array.
- 100-m forebay residence time was calculated by subtracting the time of last detection at the dam face from the time of first detection 100 m upstream of the dam face.

- Tailrace egress time was calculated by subtracting the time of last detection at the dam-face array from the time of last detection at the tailrace exit array downstream of the dam.
- Project passage time was calculated by subtracting the time of first detection on the forebay entrance array from the time of last detection on the tailrace egress array.

2.7.5 Estimation of Passage Efficiencies

Spill passage efficiency was estimated by the fraction

$$\widehat{\text{SPE}} = \frac{\hat{N}_{SP}}{\hat{N}_{SP} + \hat{N}_{SL} + \hat{N}_T},$$

where $\hat{N}_i$ is the estimated abundance of acoustically tagged fish through the *i*th route (i = spillway [SP], sluiceway, [SL], or turbines [T]). The double-detection array was used to estimate absolute abundance (*N*) through a route using the single mark-recapture model (Seber 1982:60) independently at each route. Calculating the variance in stages, the variance of $\widehat{\text{SPE}}$ was estimated as

$$\text{Var}\left(\widehat{\text{SPE}}\right) = \frac{\widehat{\text{SPE}}\left(1-\widehat{\text{SPE}}\right)}{\sum_{i=1}^{3}\hat{N}_i} + \widehat{\text{SPE}}^2\left(1-\widehat{\text{SPE}}\right)^2 \cdot \left[\frac{\text{Var}\left(\hat{N}_T\right)+\text{Var}\left(\hat{N}_{SL}\right)}{\left(\hat{N}_T+\hat{N}_{SL}\right)^2} + \frac{\widehat{\text{Var}}\left(\hat{N}_{SP}\right)}{\hat{N}_{SP}^2}\right].$$

Fish passage efficiency[1] was estimated by the fraction

$$\widehat{\text{FPE}} = \frac{\hat{N}_{SP} + \hat{N}_{SL}}{\hat{N}_{SP} + \hat{N}_{SL} + \hat{N}_T},$$

Calculating the variance in stages, the variance of $\widehat{\text{FPE}}$ was estimated as

$$\text{Var}\left(\widehat{\text{FPE}}\right) = \frac{\widehat{\text{FPE}}\left(1-\widehat{\text{FPE}}\right)}{\sum_{i=1}^{3}\hat{N}_i} + \widehat{\text{FPE}}^2\left(1-\widehat{\text{FPE}}\right)^2 \cdot \left[\frac{\text{Var}\left(\hat{N}_{SP}\right)+\text{Var}\left(\hat{N}_{SL}\right)}{\left(\hat{N}_{SP}+\hat{N}_{SL}\right)^2} + \frac{\widehat{\text{Var}}\left(\hat{N}_T\right)}{\hat{N}_T^2}\right].$$

2.7.6 Estimation of Distributions

The 3D tracks (Section 2.5) were used to determine forebay approach distributions, forebay vertical distributions, and horizontal passage distributions following the methods of Weiland et al. (2010). For the purpose of forebay approach distribution, the dam was partitioned into "arrival blocks" at a distance of 100 m from the dam—MU22–MU12; MU11–FU1; spillway south; spillway Bays 1–8; and, spillway north. The horizontal location (parallel to the face of the dam) where a tagged fish was first detected 100 m perpendicular from the dam was ascribed to an arrival block. Fish were tracked in 3D until they passed at a known portal in the dam, whence they were ascribed to a "passage block" analogous to the

[1] FPE was called spill passage efficiency in the Fish Accords.

arrival block. The data were analyzed to determine the proportions of total tagged fish approaching the dam for a given arrival block by passage block. For vertical distribution, the average depth was determined for a given 3D tracked fish within distance bins centered on 75 m, 50 m, 25 m, 10 m, and 5 m from the dam. The median depth for the population of tagged fish within a distance bin was determined and used to convey vertical distribution. Horizontal distributions were estimated by computing the proportions for each portal (turbine, sluice entrance, and spill bay or) out of total passage at a given route (turbines, sluiceway, or spillway).

3.0 Results – Yearling Chinook Salmon

This section contains estimates of survival rates, travel times, passage efficiencies, and distributions for yearling Chinook salmon at TDA during spring 2010. Capture-history data, JSATS performance, and an assessment of model assumptions for acoustically tagged yearling Chinook salmon are presented in Appendices A, B, and C, respectively.

The virtual/paired release design worked as conceived for yearling Chinook salmon. Performance of the JSATS technology was excellent as indicated by the detection probabilities at the dam-face and autonomous arrays, which were >0.99 and >0.80, respectively (Tables B.1 and B.2). The survival model assumptions were met. The distribution of fish lengths for yearling Chinook salmon revealed fewer small fish and fewer big fish were used in the tagging study than in the observed length frequency distribution sampled at JDA for the Smolt Monitoring Program (Figures E.1 and E.4). The 24-h tagging mortality was 0.20% during spring. No tags were shed during the 24-h holding period. A separate release of 50 dead yearling Chinook salmon with active tags from TDA in 2010 resulted in no downstream detections at rkm 275. Travel times were sufficiently short relative to tag life to adequately adjust the release-recapture data for tag failure (Figure E.5). In all cases, the probability that an acoustic tag was active at a downstream detection location was >0.98 (Table E.1; Figure E.7). Graphs of arrival timing (Figure E.10) indicate the release timing of the different tag groups was appropriate for adequate downstream mixing of fish. Auxiliary analyses found no tagger effects (Table E.4) that might confound estimation of dam passage survival.

3.1 Survival Estimates

The estimate of dam passage survival was based on the survival of V_1 to detection array D_1 divided by the ratio of estimates of reach survivals for fish traveling between the tailrace array (rkm 307) and D_2 and between the tailwater array (rkm 275) and D_2 (see Figure 2.1). Using the tag-life-adjusted survival estimates for yearling Chinook salmon, dam passage survival at TDA was calculated to be

$$\hat{S}_{\text{TDA}} = \frac{\hat{S}_1}{\left(\frac{\hat{S}_2}{\hat{S}_3}\right)} = \frac{0.9406}{\left(\frac{0.9710}{0.9952}\right)} = \frac{0.9406}{(0.9757)} = 0.9641$$

with an associated standard error of 0.0096 (n = 2,037). The standard error is based on both the multinomial sampling error of the release-recapture process and the sampling error associated with the estimation of the probabilities of tag activation. The estimate of dam survival for yearling Chinook salmon at TDA in 2010 exceeded the BiOp requirements for $\hat{S}_{\text{Dam}} \geq 0.96$ and of $\widehat{\text{SE}} \leq 0.015$.

The estimates of forebay-to-tailrace passage survival were calculated analogously to that of dam passage survival except the virtual-release group ($V1$) was composed of fish known to have arrived at the forebay (i.e., detection array rkm 311, Figure 2.1) rather than at the dam face. Although the capture-history data for V_1 changed (Appendix A, Table A.1), the same capture-history data were used for releases R_2 and R_3 (Appendix A, Table A.2). Using the same statistical model that was used in estimating dam passage survival, forebay-to-tailrace survival for yearling Chinook salmon was

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9620\left(\widehat{\text{SE}} = 0.0097\right)$$

As might be expected, the forebay-to-tailrace survival estimates are slightly lower than the respective estimates of dam passage survival due to the additional travel distance above the dam. The Fish Accords do not have compliance standards for either the forebay-to-tailrace survival estimates or its standard error. Nevertheless, standard errors for the estimates of dam passage survival and forebay-to-tailrace survival should be similar because of the very similar sample sizes used in both calculations.

Route-specific, dam passage survival estimates for yearling Chinook salmon were highest for the sluiceway (99.3%), followed by the spillway (96.6%) (Table 3.1). The lowest survivals were at the turbine route (87.6%).

Table 3.1. Route-Specific Dam Passage Survival Estimates for Yearling Chinook Salmon

Route	Estimate	SE	n
Turbine	0.8759	0.0355	109
Sluiceway	0.9928	0.0149	215
Spillway	0.9661	0.0099	1,712

3.2 Travel Times

Mean travel times for yearling Chinook salmon were about 1.5 h from the forebay entrance array 2 km upstream to the dam and about 1.5 h from the dam to the tailrace egress demarcation 2 km downstream (Table 3.2). The median travel time was higher for forebay residence (1.28 h) than for tailrace egress (0.39 h). Travel time for project passage from 2 km upstream of the dam to 2 km downstream averaged 3.01 h, with a median of 1.81 h.

Table 3.2. Travel Times (h) for Yearling Chinook Salmon

Metric	n	Mean	Median	Range	Max	Min	SE	75% Q3	25% Q1
Forebay Residence (CR311 to CR309)	2040	1.47	1.28	17.13	17.63	0.50	0.02	1.67	1.03
Tailrace Egress (CR309 to CR307)	1924	1.55	0.39	367.09	367.24	0.15	0.28	0.58	0.31
Project Passage (CR311 to CR307)	1925	3.01	1.81	367.80	368.67	0.87	0.28	2.35	1.47

3.3 Passage Efficiencies

For the dam as a whole, 95% of the acoustically tagged yearling Chinook salmon passed in non-turbine routes (Table 3.3). This 95% non-turbine passage out of total project passage comprised 84% at the spillway and 11% at the sluiceway. Turbine passage was 5% of the total. For the powerhouse as a whole, 67% of the yearling Chinook passed via the sluiceway.

Fish passage efficiency was 8% higher during daytime than nighttime on an absolute basis (Table 3.3). Spillway passage efficiencies were much higher (24%) during day than night. In contrast, sluiceway passage efficiency relative to the entire dam was 16% lower during day than night, because most fish passed at the spillway. Relative to the powerhouse, sluiceway passage efficiency was similar for day and night periods.

Table 3.3. Passage Efficiencies for Yearling Chinook Salmon

Metric	Period	Estimate	SE	n
Fish passage efficiency	Overall	0.9466	0.0050	2,040
	Day	0.9753	0.0043	1,296
	Night	0.8965	0.0112	744
Spill passage efficiency	Overall	0.8407	0.0081	2,040
	Day	0.9282	0.0072	1,296
	Night	0.6882	0.0170	744
Sluiceway passage efficiency relative to the powerhouse	Overall	0.6646	0.0262	325
	Day	0.6559	0.0493	93
	Night	0.6681	0.0309	232
Sluiceway passage efficiency relative to the whole dam	Overall	0.1059	0.0068	2,040
	Day	0.0471	0.0059	1,296
	Night	0.2083	0.0149	744

3.4 Distributions

This section covers forebay approach distribution, forebay vertical distribution, and horizontal distribution for yearling Chinook salmon. Forebay approach distribution for yearling Chinook salmon, based on time of first detection 100 m from the dam, was skewed toward the upstream half of the TDA powerhouse (MU 22 to MU 12), where 40% of the tagged yearling Chinook salmon first arrived (Figure 3.1). Another 23% of the total arrived at the downstream portion of the powerhouse (MU 11 to FU 1). Thirty-seven percent of the yearling Chinook salmon approached the dam at the spillway moving directly down the northern, Washington side of the forebay. Fish that approached the spillway directly passed there. Forty-three percent of the total fish arriving at the dam approached within 100 m of the powerhouse before migrating over to the spillway and passing there. Arrival distributions for yearling Chinook salmon were similar between day and night (Figure 3.1). During night, however, fish approaching the powerhouse were more likely to pass into the turbines or the sluiceway than move past the powerhouse to pass at the spillway, as observed during daytime.

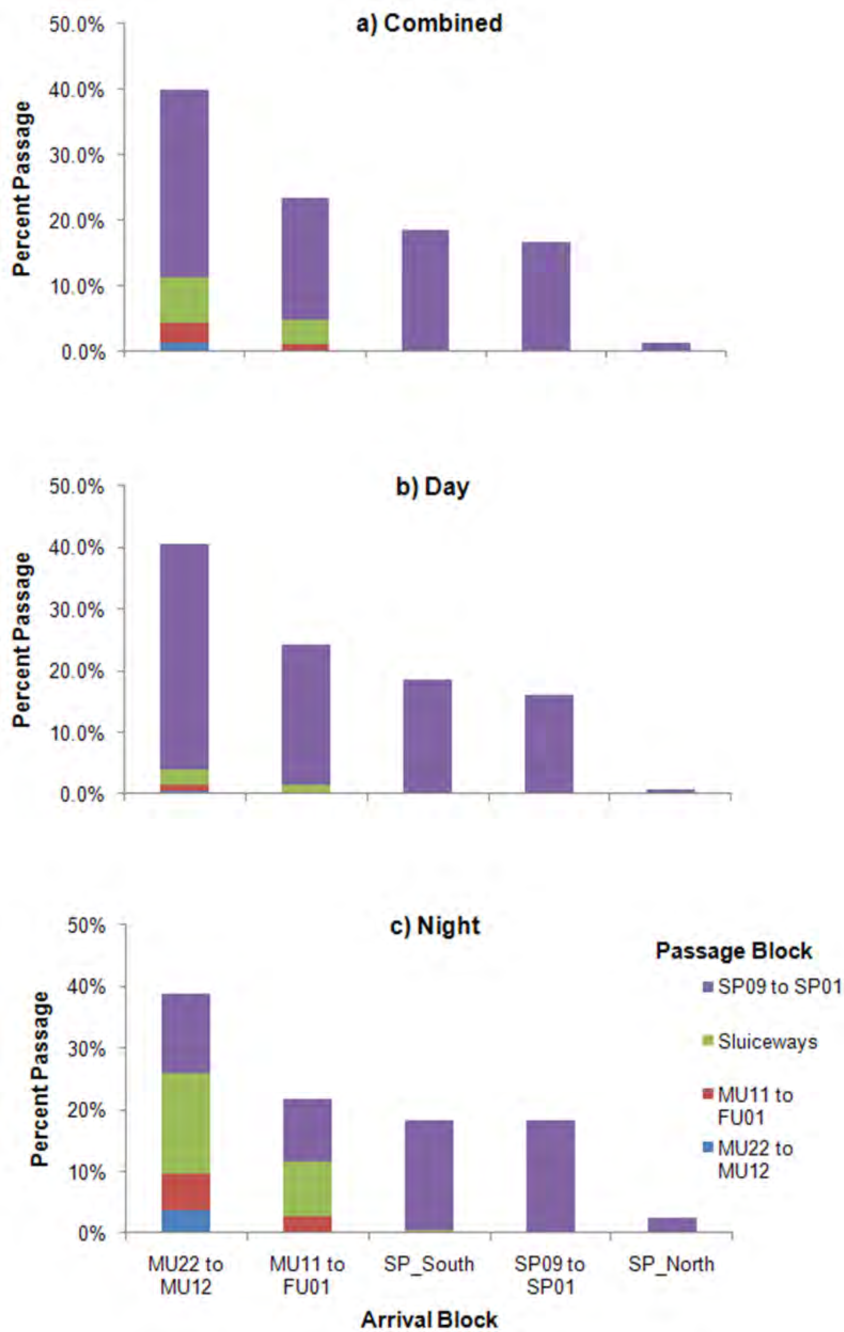


Figure 3.1. Yearling Chinook Salmon Approach and Passage Behavior Patterns at The Dalles Dam During 2010: a) Day/Night Combined; b) Day; and c) Night. The sum of the percent passages for the arrival blocks equals 100%. The sum of the percentages across all arrival blocks for a given passage block equals its passage efficiency (Table 3.3).

Forebay vertical distribution, as indicated by the median depths of last detection by distance from the dam where fish passed, showed at least 50% of the tagged yearling Chinook salmon were in the surface 5 m of water in most locations (Figure 3.2). Vertical distribution was relatively constant as distance to the dam decreased for fish passing at the downstream half of the powerhouse, the southern spillway, and

Bays 1–9. At the spillway north location, fish moved up in the water column to pass the dam. At the upstream half of the powerhouse (MU 12–22), fish sounded to pass the dam. Vertical distribution patterns were similar between day and night, although median depth was 1 to 2 m shallower during night than during day (Figure 3.2).

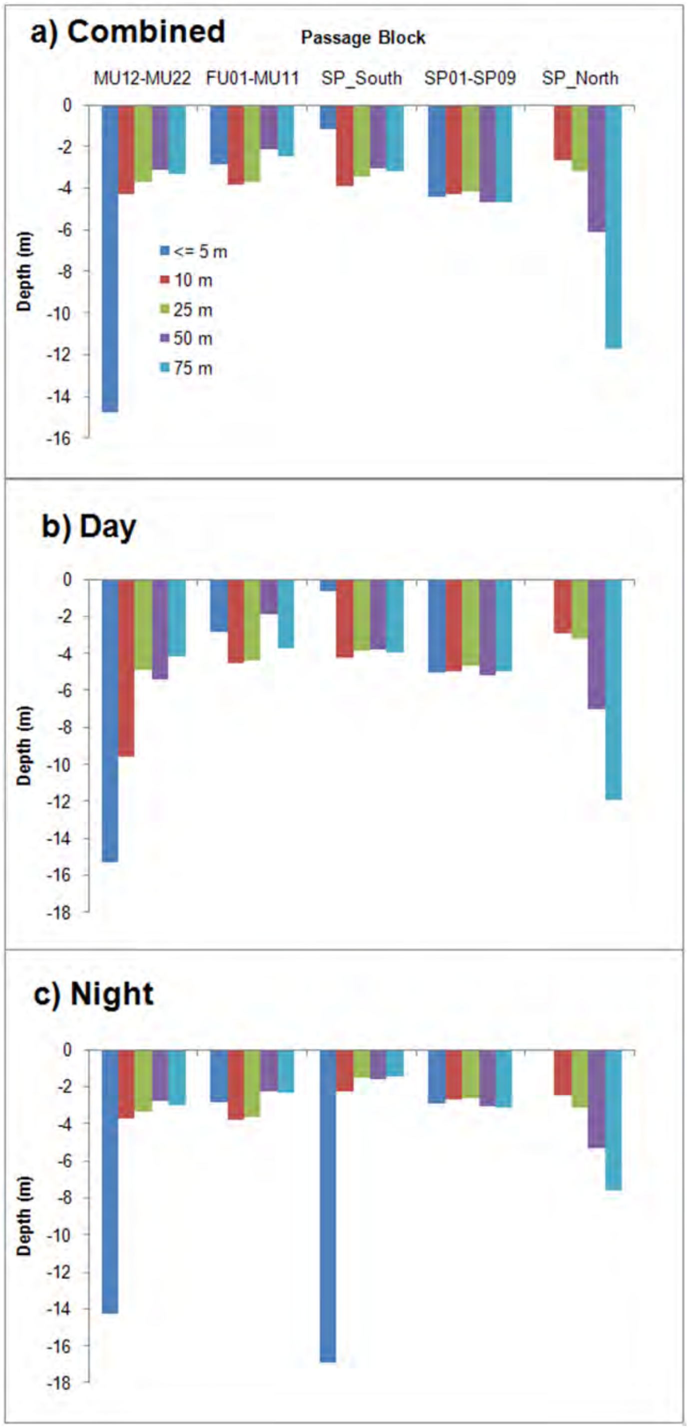


Figure 3.2. Forebay Vertical Distribution as Indicated by Median Depths of Last Detection by Distance (see legend) by Passage Block (location) from The Dalles Dam for Tagged Yearling Chinook Salmon During 2010

Horizontal distribution of yearling Chinook salmon turbine passage was skewed to the downstream end of the powerhouse where 50% of total turbine passage took place at FU 1–MU 2 (Figure 3.3). At the sluiceway, 99% of total passage was at Sluice 1-1, 1-2, and 1-3, the sluiceway entrances above MU 1. Horizontal distribution of yearling Chinook salmon passage at the spillway was dominated by Bay 8, with 40% of total passage at Bays 1–8.

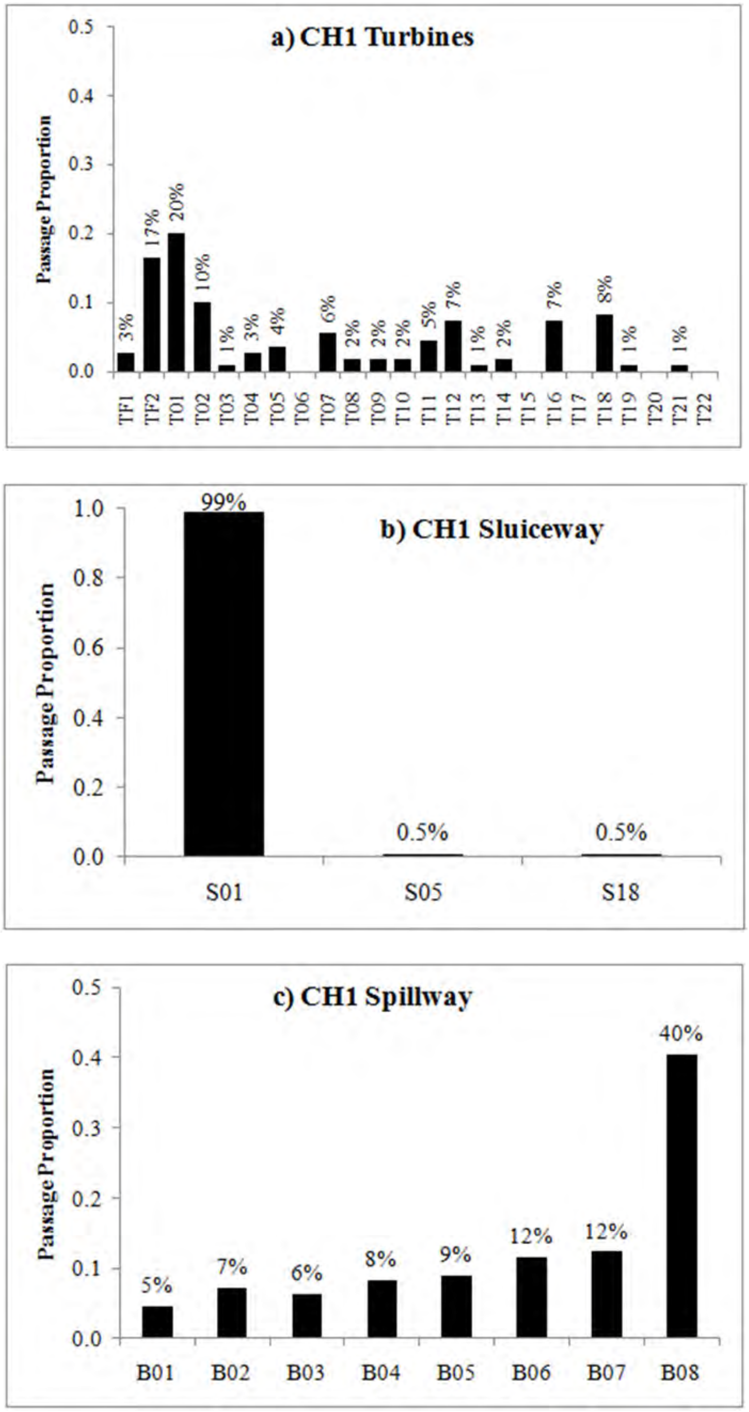


Figure 3.3. Horizontal Distribution of Passage for Yearling Chinook Salmon at the Turbines, Spillway (Bays 1–8 only), and Sluiceway

4.0 Results – Steelhead

This section contains estimates of survival rates, travel times, passage efficiencies, and distributions for steelhead at TDA during spring 2010. Capture-history data, JSATS performance, and an assessment of model assumptions for acoustically tagged steelhead are presented in Appendices A, B, and C, respectively.

The virtual/paired-release design worked as conceived for steelhead. Performance of the JSATS technology was excellent as indicated by the detection probabilities at the dam-face and autonomous arrays, which were >0.99 and >0.74, respectively (Tables B.1 and B.2). The survival model assumptions were met. The distribution of fish lengths for steelhead smolts used in the tagging study was comparable to the ROR steelhead sampled at JDA for the Smolt Monitoring Program (Figures E.2 and E.4). The 24-h tagging mortality was 0.20% during spring. As with yearling Chinook salmon, no tags were shed during the 24-h holding period. A separate release from TDA of 50 dead steelhead with active tags resulted in no downstream detections at rkm 275. Travel times were sufficiently short relative to tag life to adequately adjust the release-recapture data for tag failure (Figure E.5). In all cases, the probability that an acoustic tag was active at a downstream detection location was >0.98 (Table E.2; Figure E.8). Graphs of arrival timing (Figure E.11) indicate the release timing of the different tag groups was appropriate for adequate downstream mixing of fish. Auxiliary analyses found no tagger effects (Table E.5) that might confound estimation of dam passage survival for steelhead.

4.1 Survival Estimates

Using the tag-life-adjusted survival estimate for the three release groups, dam passage survival for steelhead smolts at TDA was estimated to be

$$\hat{S}_{\text{TDA}} = \frac{0.9527}{\left(\dfrac{0.9785}{0.9792}\right)} = \frac{0.9527}{0.9993} = 0.9534$$

with an associated standard error of 0.0097 (n = 2,038). Although the estimated standard error met the BiOp requirement of $\widehat{\text{SE}} \le 0.015$, the point estimate for steelhead did not meet the BiOp requirement of $\hat{S} \ge 0.96$. Using the same statistical model that was used in estimating dam passage survival, forebay-to-tailrace survival for steelhead was

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9526\left(\widehat{\text{SE}} = 0.0097\right).$$

Route-specific, dam passage survival estimates for steelhead were highest for the spillway (95.3%), followed by the sluiceway (94.4%) (Table 4.1). The lowest survivals were at the turbine route (88.8%).

Table 4.1. Route-Specific Dam Passage Survival Estimates for Steelhead

Route	Estimate	SE	n
Turbine	0.8875	0.0339	95
Sluiceway	0.9443	0.0204	157
Spillway	0.9583	0.0098	1795

4.2 Travel Times

Mean travel times for steelhead were almost 3 h from the forebay entrance array 2 km upstream to the dam and about 1.2 h from the dam to the tailrace egress demarcation 2 km downstream (Table 4.2). The median travel time was higher for forebay residence (1.28 h) than for tailrace egress (0.35 h). Travel time for project passage from 2 km upstream of the dam to 2 km downstream averaged 3.87 h, with a median of 1.81 h.

Table 4.2. Travel Times (h) for Steelhead

Metrics	n	Mean	Median	Range	Max	Min	SE	75% Q3	25% Q1
Forebay Residence (CR311 to CR309)	2046	2.78	1.28	259.28	259.74	0.46	0.23	2.03	0.91
Tailrace Egress (CR309 to CR 307)	1938	1.17	0.35	311.82	311.96	0.14	0.24	0.46	0.28
Project Passage (CR311 to CR307)	1937	3.87	1.81	312.09	312.83	0.74	0.31	2.82	1.29

4.3 Passage Efficiencies

For the dam as a whole, 95% of the acoustically tagged steelhead passed via non-turbine routes (Table 4.3). This 95% non-turbine passage out of total project passage comprised 88% at the spillway and 7% at the sluiceway. Turbine passage was 5% of the total. For the powerhouse as a whole, 62% of the steelhead passed via the sluiceway.

Non-turbine FPE was 7% higher during daytime than nighttime on an absolute basis (Table 4.3). Spillway passage efficiencies were much higher (19%) during day than night. In contrast, sluiceway passage efficiency relative to the entire dam was 10% lower during day than night, but relative to the powerhouse, it was similar during the day and night.

Table 4.3. Passage Efficiencies for Steelhead

Metric	Time	Estimate	SE	n
Fish passage efficiency	Overall	0.9536	0.0046	2,048
	Day	0.9832	0.0036	1,250
	Night	0.9073	0.0103	798
Spill passage efficiency	Overall	0.8770	0.0073	2,048
	Day	0.9456	0.0064	1,250
	Night	0.7694	0.0149	798
Sluiceway passage efficiency relative to the powerhouse	Overall	0.6230	0.0305	252
	Day	0.6912	0.0560	68
	Night	0.5978	0.0361	184
Sluiceway passage efficiency relative to the whole dam	Overall	0.0767	0.0059	2,048
	Day	0.0376	0.0054	1,250
	Night	0.1378	0.0122	798

4.4 Distributions

This section covers forebay approach distribution, forebay vertical distribution, and horizontal distribution for steelhead. Forebay approach distribution for steelhead, based on time of first detection 100 m from the dam, was skewed to the upstream half of the TDA powerhouse (MU 22 to MU 12), where 40% of the tagged steelhead first arrived (Figure 4.1). Another 19% of the total arrived at the downstream portion of the powerhouse (MU 11 to FU 1). Forty-one percent of the steelhead approached the dam at the spillway moving directly down the northern, Washington side of the forebay. Fish that approached the spillway directly passed there. Forty-six percent of the total steelhead arriving at the dam approached within 100 m of the powerhouse before migrating over to the spillway and passing there. Arrival distributions for steelhead at MU 22–MU 12 showed an 11% absolute decrease between night (48%) and day (37%) (Figure 4.1). Fish approaching the powerhouse during night were more likely to pass into the turbines or the sluiceway than move past the powerhouse to pass at the spillway, as observed during daytime.

Forebay vertical distribution, as indicated by the median depths of last detection by distance from the dam where fish passed, showed at least 50% of the tagged steelhead were in the surface 4 m of water in most locations (Figure 4.2). The median depth was about 1 m shallower on approach to the spillway than on approach to the powerhouse. Vertical distribution was relatively constant as distance to the dam decreased for fish passing at Bays 1–9. The steelhead moved up in the water column as they approached and passed at the downstream portion of the powerhouse and northern spillway. At the spillway north location, fish moved up in the water column to pass the dam. At the upstream portion of the powerhouse (MU 12–22), fish sounded to pass the dam during night but not during day. Vertical distributions were 2 to 3 m shallower during day than night (Figure 4.2).

Horizontal distribution of steelhead turbine passage was skewed to the downstream end of the powerhouse where 35% of total turbine passage took place at FU 1–MU 2 (Figure 4.3). At the sluiceway, 94% of total passage was at Sluice 1-1, 1-2, and 1-3, the sluiceway entrances above MU 1. Horizontal distribution of steelhead passage at the spillway was dominated by Bay 8 with 36% of total passage at Bays 1–8.

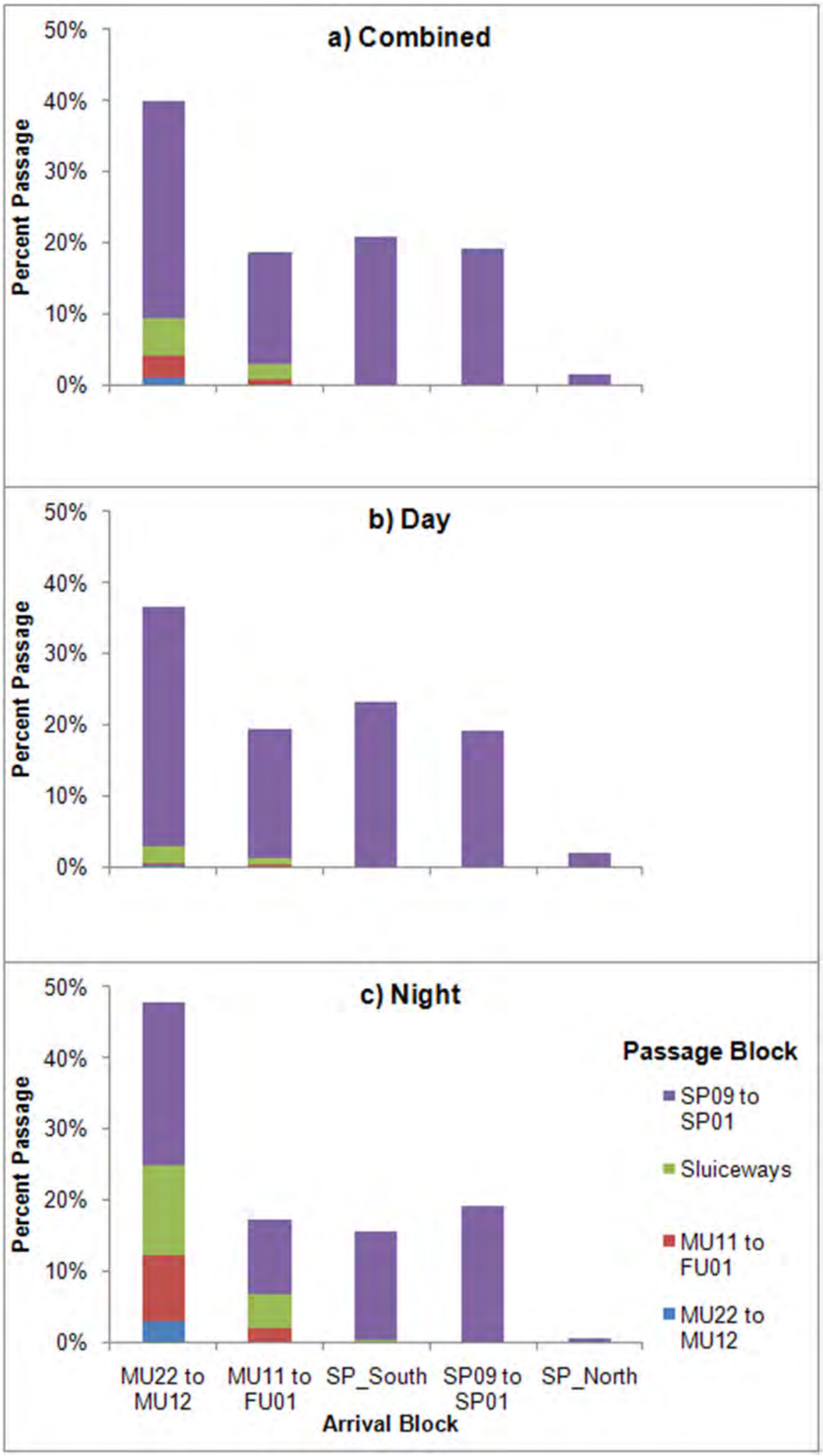


Figure 4.1. Steelhead Approach and Passage Behavior Patterns at The Dalles Dam During 2010: a) Day/Night Combined; b) Day; and c) Night. The sum of the percent passages for the arrival blocks equals 100%. The sum of the percentages across all arrival blocks for a given passage block equals its passage efficiency (Table 4.3).

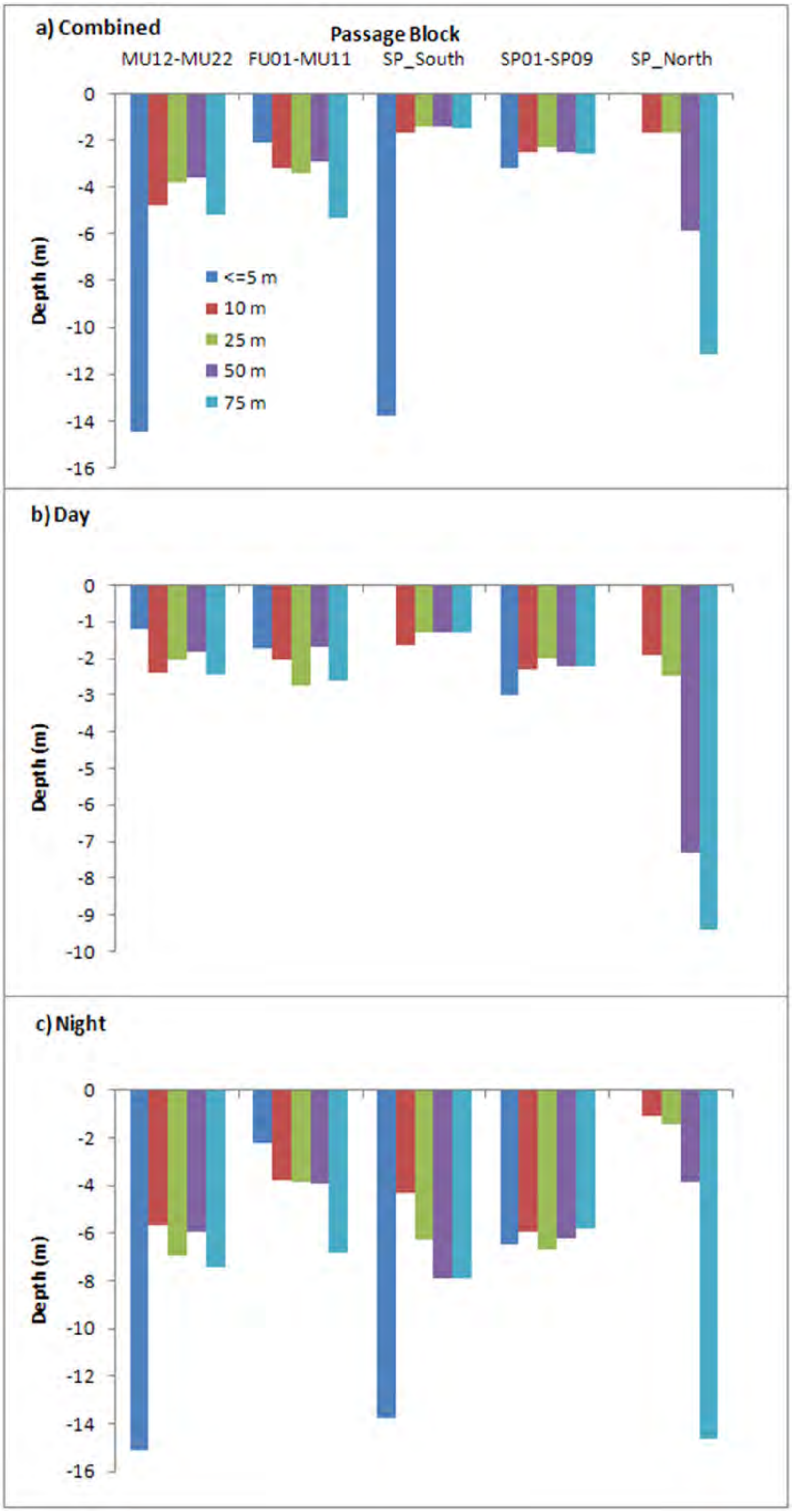


Figure 4.2. Forebay Vertical Distribution as Indicated by Median Depths of Last Detection by Distance (see legend) by Passage Block (location) from The Dalles Dam for Steelhead at The Dalles Dam During 2010: a) Day/Night Combined; b) Day; and c) Night

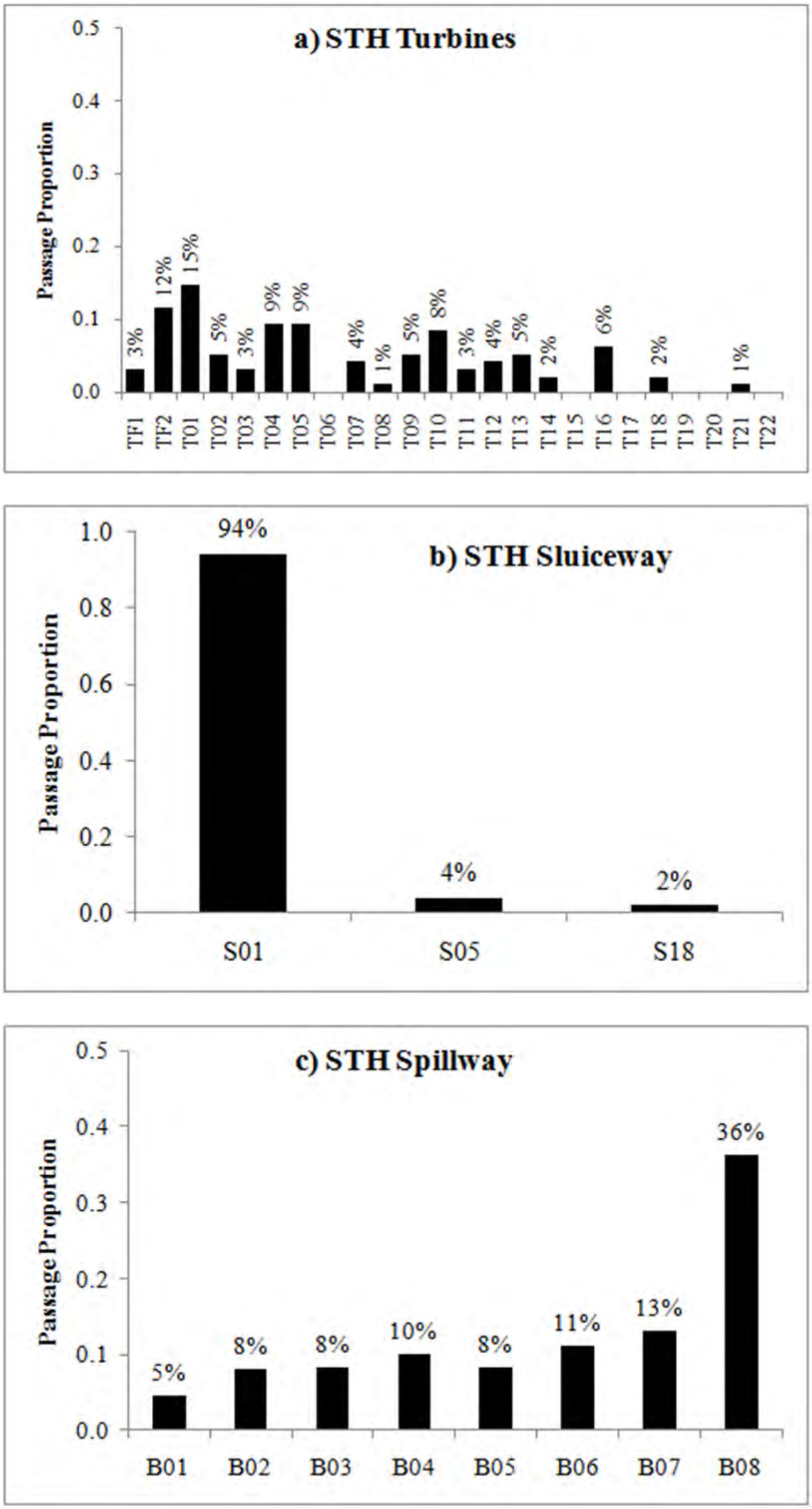


Figure 4.3. Horizontal Distribution of Passage for Steelhead at the a) Turbines, b) Spillway (Bays 1–8 only), and c) Sluiceway

5.0 Results – Subyearling Chinook Salmon

This section contains estimates of survival rates, travel times, passage efficiencies and distributions for acoustically tagged subyearling Chinook salmon at TDA during summer 2010. Capture-history data, JSATS performance, and an assessment of model assumptions for acoustically tagged subyearling Chinook salmon are presented in Appendices A, B, and C, respectively.

The virtual/paired release design worked as conceived for subyearling Chinook salmon. Performance of the JSATS technology was excellent as indicated by the detection probabilities at the dam-face and autonomous arrays, which were >0.99 and >0.85, respectively (Tables B.1 and B.2). The survival model assumptions were met. The distribution of fish lengths for subyearling Chinook salmon used in the tagging study was comparable to the ROR subyearling Chinook salmon sampled at JDA for the Smolt Monitoring Program, except that fish less than 95 mm long were not included in the tagging study (Figures E.3 and E.4). Handling mortality and tag shedding was negligible. A separate release of 21 dead subyearling Chinook salmon with active tags from TDA in 2010 resulted in no downstream detections at rkm 275. Travel times were sufficiently short relative to tag life to adequately adjust the release-recapture data for tag failure (Figure E.6). In all cases, the probability that an acoustic tag was active at a downstream detection location was >0.99 (Table E.3; Figure E.9). In other words, for the summer investigation, very little tag-life correction was needed to produce unbiased survival estimates. Graphs of arrival timing (Figure E.12) indicate the release timing of the different tag groups was appropriate for adequate downstream mixing of fish. Auxiliary analyses found no tagger effects (Table E.6) that might confound estimation of dam passage survival for subyearling Chinook salmon.

5.1 Survival Estimates

The estimate of dam passage survival was based on the survival of V_1 to detection array D_1 divided by an estimate of reach survival between the tailrace array (rkm 307) and D_1. Using the tag-life-adjusted survival estimates for subyearling Chinook salmon (Table 3.4), dam passage survival at TDA was calculated to be

$$\hat{S}_{\text{TDA}} = \frac{\hat{S}_1}{\left(\dfrac{\hat{S}_2}{\hat{S}_3}\right)} = \frac{0.9210}{\left(\dfrac{0.9707}{0.9912}\right)} = \frac{0.9210}{0.9793} = 0.9404$$

with an associated standard error of 0.0091 (n = 2,417). Using the same statistical model as was used in estimating dam passage survival, forebay-to-tailrace survival for subyearling Chinook salmon was estimated to be

$$\hat{S}_{\text{Forebay-to-tailrace}} = 0.9356\left(\widehat{\text{SE}} = 0.0092\right).$$

Route-specific, dam passage survival estimates for subyearling Chinook salmon were highest for the sluiceway (97.8%), followed by the spillway (95.5%) (Table 5.1). The lowest survivals were at the turbine route (86.2%).

Table 5.1. Route-Specific Dam Passage Survival Estimates for Subyearling Chinook Salmon

Route	Estimate	SE	n
Turbine	0.8621	0.0194	411
Sluiceway	0.9780	0.0143	284
Spillway	0.9545	0.0095	1719

5.2 Travel Times

Mean travel times for subyearling Chinook salmon were about 1.5 h from the 2-km forebay entrance demarcation to the dam and about 2.1 h from the dam to the tailrace egress demarcation 2 km downstream (Table 5.2). The median travel time was higher for forebay residence (1.20 h) than for tailrace egress (0.32 h). Travel time for project passage from 2 km upstream of the dam to 2 km downstream averaged 3.54 h, with a median of 1.66 h.

Table 5.2. Travel Times (h) for Subyearling Chinook Salmon

Metric	n	Mean	Median	Range	Max	Min	SE	75% Q3	25% Q1
Forebay Residence (CR311 to CR309)	2409	1.50	1.20	171.79	172.20	0.41	0.10	1.54	0.93
Tailrace Egress (CR309 to CR307)	2054	2.10	0.32	324.50	324.61	0.11	0.38	0.59	0.23
Project Passage (CR311 to CR 307)	2050	3.54	1.66	324.66	325.47	0.81	0.39	2.12	1.37

5.3 Passage Efficiencies

For the dam as a whole, 83% of the acoustically tagged subyearling Chinook salmon passed in non-turbine routes (Table 5.3). This 83% non-turbine passage out of total project passage comprised 71% at the spillway and 12% at the sluiceway. Turbine passage was 17% of the total for the project. For the powerhouse as a whole, 41% of the subyearling Chinook salmon passed via the sluiceway.

Non-turbine FPE was 28% higher during daytime than nighttime on an absolute basis (Table 5.3). Spillway passage efficiencies were much higher (28%) during day than night. In contrast, sluiceway passage efficiency relative to total project passage was comparable between day and night. Relative to the powerhouse, sluiceway passage efficiency was 40% higher during day than night on an absolute basis.

Table 5.3. Passage Efficiencies for Subyearling Chinook Salmon

Metric	Period	Estimate	SE	n
Fish passage efficiency	Overall	0.8298	0.0076	2,415
	Day	0.9353	0.0064	1,500
	Night	0.6568	0.0157	915
Spill passage efficiency	Overall	0.7122	0.0092	2,415
	Day	0.8173	0.0100	1,500
	Night	0.5399	0.0165	915
Sluiceway passage efficiency relative to the powerhouse	Overall	0.4086	0.0186	695
	Day	0.6460	0.0289	274
	Night	0.2542	0.0212	421
Sluiceway passage efficiency relative to the whole dam	Overall	0.1176	0.0066	2,415
	Day	0.1180	0.0083	1,500
	Night	0.1169	0.0106	915

5.4 Distributions

This section covers forebay approach distribution, forebay vertical distribution, and horizontal distribution for subyearling Chinook salmon. Forebay approach distribution for subyearling Chinook salmon, based on time of first detection 100 m from the dam, was skewed to the upstream half of the TDA powerhouse (MU 22 to MU 12), where 55% of the tagged subyearling Chinook salmon first arrived (Figure 5.1). Another 19% of the total arrived at the downstream portion of the powerhouse (MU 11 to FU 1). Twenty-six percent of the subyearling Chinook salmon approached the dam at the spillway moving directly down the northern, Washington side of the forebay. Fish that approached the spillway directly passed there. Fifty-eight percent of the total subyearling Chinook salmon arriving at the dam approached within 100 m of the powerhouse before migrating over to the spillway and passing there. Arrival distributions for subyearling Chinook salmon were similar between day and night (Figure 5.1). During night, however, fish approaching the powerhouse were more likely to pass into the turbines or the sluiceway than they were to move past the powerhouse to pass at the spillway, as observed during daytime.

Forebay vertical distribution, as indicated by the median depths of last detection by distance from the dam where fish passed, showed at least 50% of the tagged subyearling Chinook salmon were in the surface 6 m of water in most locations (Figure 5.2). Vertical distribution was relatively constant as distance to the dam decreased for fish passing at the downstream half of the powerhouse, the southern spillway, and Bays 1–9. At the spillway north location, fish moved up in the water column to pass the dam. At the upstream half of the powerhouse (MU 12–22), fish sounded to pass the dam. Vertical distribution was 2 to 3 m deeper during night than it was during day. Subyearling Chinook salmon moved up in the water column during night to pass the dam at the spillway (Bays 1–8) and the downstream powerhouse (FU 1–MU 11) (Figure 5.2).

Horizontal distribution of subyearling Chinook salmon turbine passage was relatively uniform (Figure 5.3). At the sluiceway, 95% of total passage was at Sluices 1-1, 1-2, and 1-3, the sluiceway entrances above MU 1. Horizontal distribution of subyearling Chinook salmon passage at the spillway was dominated by Bay 8 with 26% of total passage through Bays 1–8.

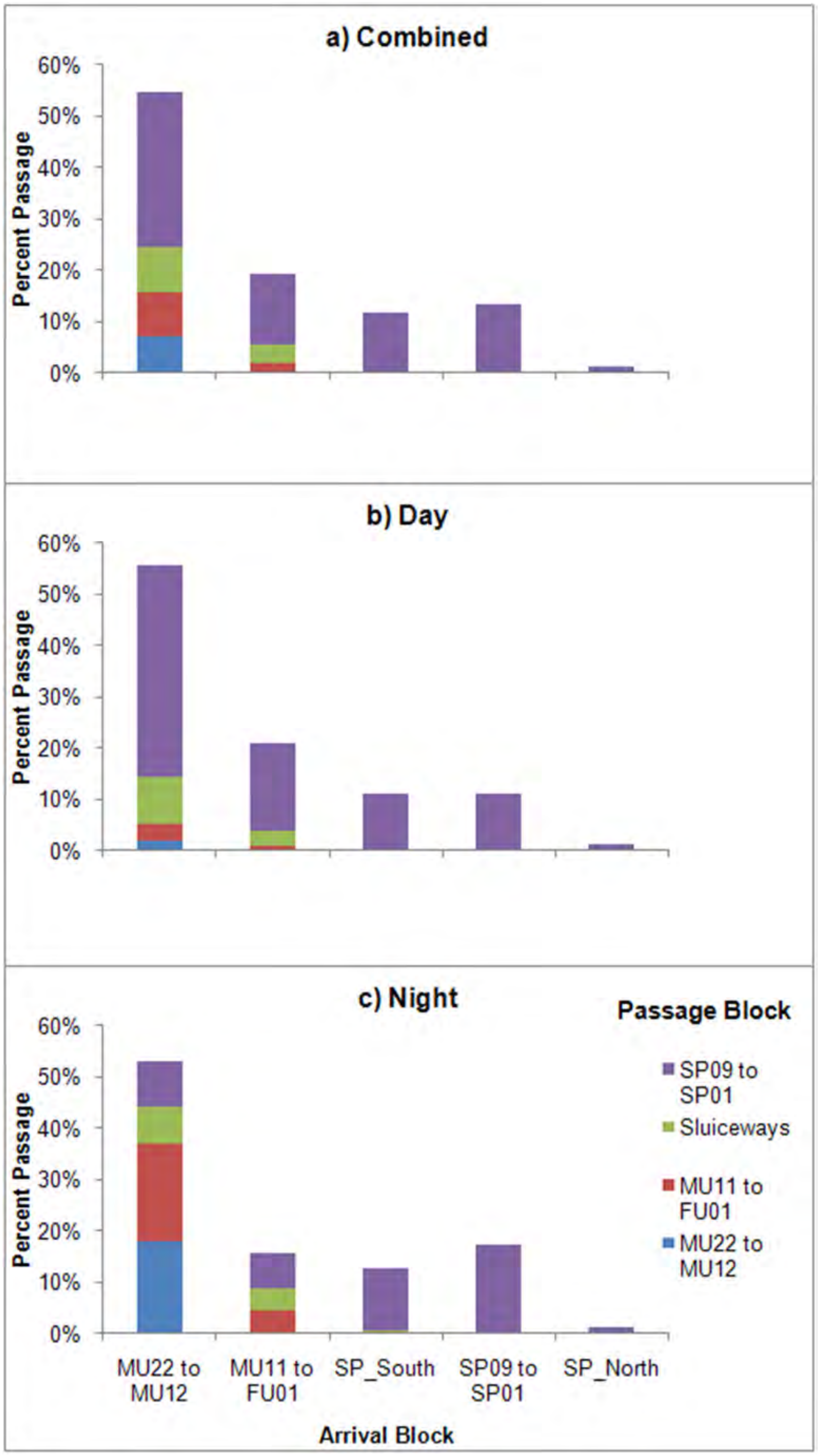


Figure 5.1. Subyearling Chinook Salmon Approach and Passage Behavior Patterns at The Dalles Dam During 2010: a) Day/Night Combined; b) Day; and c) Night. The sum of the percent passages for the arrival blocks equals 100%. The sum of the percentages across all arrival blocks for a given passage block equals its passage efficiency (Table 5.3).

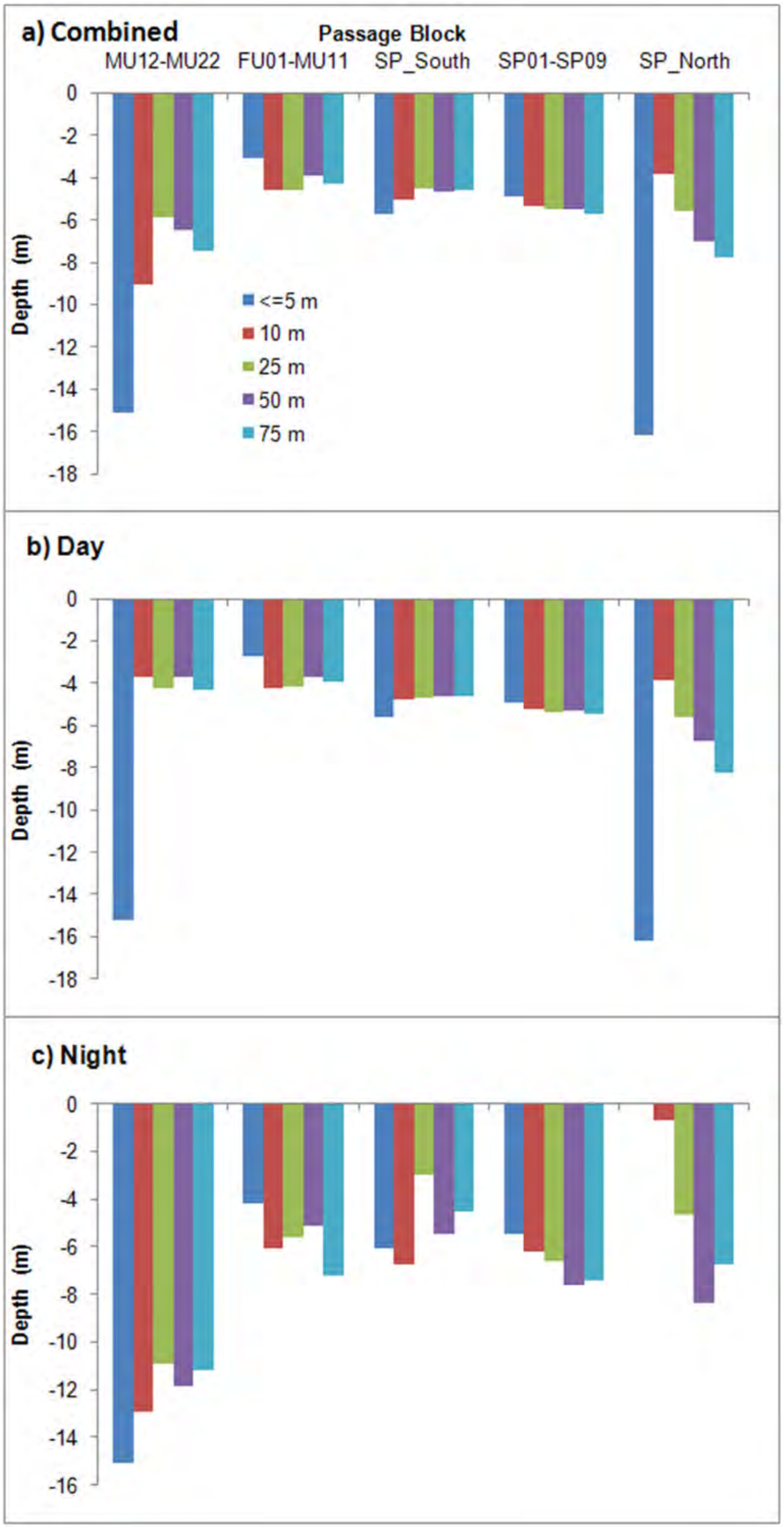


Figure 5.2. Forebay Vertical Distribution as Indicated by Median Depths of Last Detection by Distance (see legend) by Passage Block (location) from The Dalles Dam of Tagged Subyearling Chinook Salmon During 2010: a) Day/Night Combined; b) Day; and c) Night

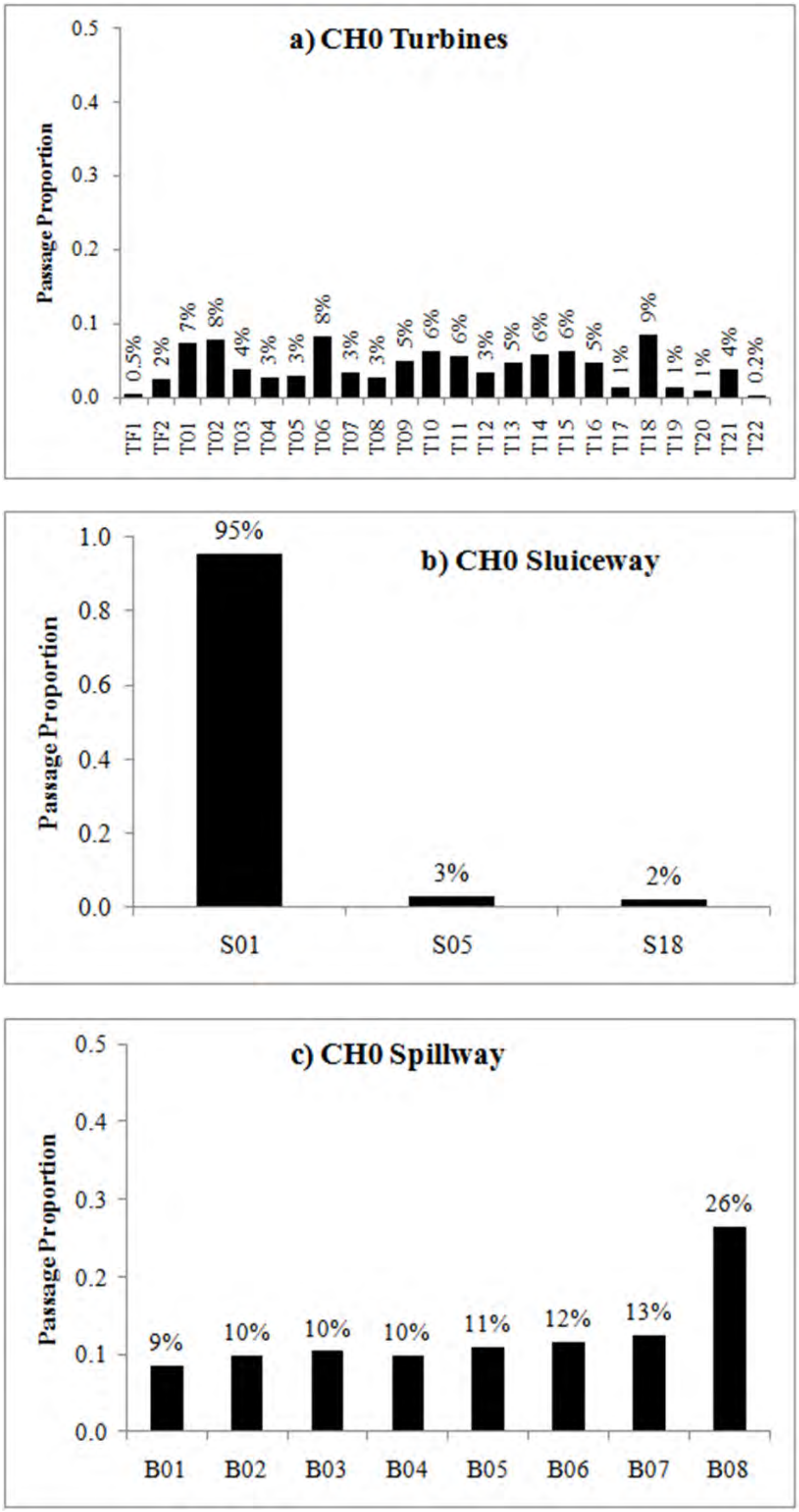


Figure 5.3. Horizontal Distribution of Passage for Yearling Chinook Salmon at the a) Turbines, b) Spillway (Bays 1–8 only), and c) Sluiceway

6.0 Discussion

This section includes discussion of statistical performance and survival model assumptions, historical context, performance of the new spill wall, sluiceway passage and survival, and conclusions and recommendations.

6.1 Statistical Performance and Survival Model Assumptions

The BiOp requires estimates of dam passage survival with standard errors ≤ 0.015. The numbers of tagged fish released (Table 2.1) and the detection probabilities at the downstream hydrophone arrays (Tables B.1 and B.2) in spring 2010 were found to be adequate to achieve this precision requirement. Estimated standard errors for yearling Chinook salmon and steelhead were <0.01. Therefore, the number of tagged fish released for the survival studies in future years should be comparable to those used in 2010 to help ensure precision requirements will be achieved. If levels of hydrophone deployment change, the number of fish tagged may need to be reassessed.

The survival study at TDA is the first full-scale application of the virtual/paired-release design of Skalski et al. (2010) in the FCRPS. The virtual/paired-release design worked as conceived. The virtual-release group (V_1) estimated smolt passage survival from the dam face to a downriver detection array at rkm 275. The array at rkm 275 was selected because it was sufficiently downriver to ensure any fish that died during dam passage with a still active tag would not be detected on downstream arrays. A separate release of 41 dead fish (20 in spring and 21 in summer) with active tags from TDA in 2010 resulted in no downstream detections at rkm 275. To account for the extra mortality between the tailrace and the detection array at rkm 275, a paired release using groups R_2 and R_3 was used to estimate reach survival in the upper part of the Bonneville reservoir. The quotient of the survival estimates from the virtual release (V_1) and paired release (R_2 and R_3) was the basis for the estimates of dam passage survival in this report.

In this first year of compliance testing, detection data from all of the downstream detection arrays to the mouth of the Columbia River were used in the analysis. This was done intentionally to assure everyone that all available information was used in the survival analysis. However, with individual hydrophones often having detection probabilities much greater than 0.90, little additional information is truly available in the far-field arrays. A separate sensitivity analysis supports this conclusion. In future years, only the three nearest downstream hydrophone arrays will be used in the survival analysis to simplify procedures and avoid any perceived conflicts due to apparent arbitrary detection array selection.

6.2 Historical Context

Historically, telemetry studies have been used to estimate survival rates for yearling Chinook salmon passing TDA. For radio-tag studies conducted during 2002, 2004, and 2005 (Counihan et al. 2006a, b, c), survival estimates were generated using the route-specific survival model for radio-tagged fish released by boat in the tailraces of JDA (treatment) and TDA (control). As summarized by Johnson et al. (2007, p. 7.4), the mean dam survival rate for yearling Chinook salmon over the three study years was 0.904.

During the yearling Chinook salmon migration in spring 2006, an acoustic-tag study was used to estimate passage survival at TDA (Ploskey et al. 2007). The estimation process involved releases from the JDA and TDA tailraces along with downstream detections at TDA primary (rkm 275), TDA secondary (rkm 234), and BON primary (rkm 153) arrays. Project passage survival was estimated to be 0.928 (SE = 0.013) for yearling Chinook salmon. Steelhead were not tagged in 2006.

Weiland et al. (2010) performed acoustic-tag studies for fish passage and survival at JDA during 2008 and 2009 that included releases and downstream detection arrays allowing for estimation of survival between forebay arrays at TDA and BON. Specifically, tagged fish were released near Arlington, Oregon (rkm 390), and in the JDA tailrace (rkm 343.4), and regrouped on TDA forebay entrance array to create virtual releases for estimating single-release dam passage survival rates for TDA. Tag-life-corrected survival rates from 2 km upstream of TDA to the BON forebay, estimated for yearling and subyearling Chinook salmon and steelhead using a single-release model, were as follows (±½ 95% CI):

Year	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
2008	0.947 ± 0.007	0.959 ± 0.009	0.931 ± 0.013
2009	0.947 ± 0.007	0.953 ± 0.008	0.789 ± 0.051

Thus, the 2010 dam passage survival estimates of 0.9641 for yearling Chinook salmon and 0.9534 for steelhead are comparable to previous estimates, and were similar for the two tagged spring migrants. Although the 2010 results are new, they may not be unexpected. Passage survivals of yearling Chinook salmon and steelhead are often similar, and this was the case for this acoustic-tag study. Estimates of dam passage survival for the yearling Chinook salmon and steelhead were not significantly different $\left(P\left(|Z| \geq 0.7767\right) = 0.4373\right)$ at TDA in 2010. The 2010 dam passage survival of 0.9404 for subyearling Chinook salmon is higher than recent estimates of passage survival from 2008 and 2009 for TDA.

6.3 Performance of the New Spill Wall

The purpose of the new spill wall was to improve survival rates by minimizing the predation on spillway-passed juvenile salmon and steelhead that occurs in the vicinity of the bridge and basin islands downstream of the dam by guiding them directly to the thalweg downstream of the spillway. To examine the performance of the new spill wall constructed in winter 2009/2010, we compared survival estimates and egress rates from studies before and after the wall was installed. This approach is useful, although cause-and-effect determinations are not possible with such data. Route-specific survival rates were higher and egress rates were lower with the wall in place than without it (Table 6.1). Improved survival rates could be related to faster egress rates by reducing the likelihood of predation (Shively et al. 1996) in the region downstream of TDA where piscivorous fishes are known to reside (Duran et al. 2003). Faler et al. (1988) found northern pikeminnow avoided the high flow associated with spill gate operation in the tailrace of McNary Dam. The faster egress times for subyearling Chinook salmon in summer are particularly encouraging because the consumption rates of northern pikeminnow (*Ptychocheilus oregonensis*) and smallmouth bass (*Micropterus dolomieu*) tend to be higher in summer than spring (Vigg et al. 1991), perhaps because of higher water temperatures (Petersen and Ward 1999). Predation was also likely minimized by the dogleg at the downstream end of the spill wall that redirected spillway flow toward the Washington side of the main channel and away from habitats for piscivorous fishes in the bridge and basin islands (Martinelli and Shively 1997). By all indications from our 2010 acoustic telemetry study, the new spill wall performed well and contributed to achieving BiOp compliance.

Table 6.1. Summary of Spillway Egress Rates Before (Pre-2010) and After the New Spill Wall (2010). Data for 2002, 2004, and 2005 were obtained from Table 4.4 (Egress Rates) and Table 7.2 (Survival Estimates) from Johnson et al. (2007). Data for 2010 are highlighted in red font for emphasis.

Year	Technique	Species	Spillway Survival Estimate	Egress Rate (km/h)	Egress Passage Location
2002	RT	CH1	0.882	6.3	Bay 4
				5.2	Bay 9
				4.5	Bay 13
2004	RT	CH1	0.909	2.7	Spillway[a]
		CH0	0.916, 0.860	2.4	Spillway[a]
2005	RT	CH1	0.938	9.7	Bays 1-4
				7.7	Bays 5-6
		CH0	0.925	8.9	Bays 1-4
				7.1	Bays 5-6
2010	AT	CH1	0.966	1.3	Bays 1-8
		STH	0.958	1.7	Bays 1-8
		CH0	0.955	1.0	Bays 1-8

(a) Bays not reported.

6.4 Sluiceway Passage and Survival

The sluiceway at TDA continued to provide an important non-turbine passage route at the powerhouse. For the powerhouse as a whole, 67, 62, and 41% of the yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively, passed via the sluiceway in 5% of total powerhouse discharge. This corresponds to fish-to-flow ratios (sluiceway effectiveness) of 13.4, 12.4, and 8.2, respectively, that are among the highest in Columbia-Snake river system (Johnson and Dauble 2005). For context at TDA, fish-to-flow ratios for the spillway were 2.1, 2.2, and 1.8 for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively. This implies surface flow outlets at the spillway could conceivably pass as many fish in less flow leaving more water for power generation.

The sluiceway also had the highest route-specific survival rates for yearling and subyearling Chinook salmon among the three routes at TDA—turbines, sluiceway, and spillway. Operating the sluiceway in early spring before voluntary fish spill starts and in late summer and fall after fish spill ends provides an efficient and effective non-turbine passage route for juvenile salmonids migrating outside the peak spring and summer migration periods at TDA. Using the sluiceway to protect these fish should increase their chances of survival and help promote enhanced life history diversity, an important aspect of salmon resiliency (Waples et al. 2009).

6.5 Conclusions and Recommendations

The structural and operational configuration of TDA during 2010 complied with BiOp performance standards (NOAA Fisheries 2008) for yearling and subyearling Chinook salmon, and nearly so for juvenile steelhead. The new spill wall seemed to improve egress conditions. We recommend the same study design be executed in a new and different water-year and for new and different juvenile salmon and steelhead migrations. Survival studies for purposes of BiOp compliance must take place over multiple years to account for annual variation in physical and biological conditions.

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Appendix A

JSATS Performance

Appendix A

JSATS Performance

Appendix A contains data on the detection probabilities at the dam-face arrays and the autonomous arrays.

A.1 Detection Probabilities at Dam-Face Arrays

Detection probabilities for the dam-face arrays used in the 2010 TDA survival study were greater than 98% for all three tagged species (Table A.1).

Table A.1. Detection Probabilities for the Dam-Face Arrays (N11 = detected on both arrays; N10 = detected on array 1 but not array 2; N01 = detected on array 2 but not array 1)

Species	Number Released Above TDA	N11	N10	N01	Detection Probability Array 1	Detection Probability Array 2	Combined Probability
CH1	2445	2341	26	15	0.9936	0.9890	0.9999
STH	2448	2305	14	7	0.9970	0.9940	1.0000
CH0	2483	2351	3	5	0.9979	0.9987	1.0000

A.2 Detection Probabilities at Autonomous Nodes

Detection probabilities for the autonomous arrays were greater than 80% for yearling Chinook salmon, greater than 74% for steelhead, and greater than 85% for subyearling Chinook salmon (Table A.2).

Table A.2. Detection Probabilities for the Autonomous Arrays. Standard errors for the estimates are in parentheses.

	Yearling Chinook	Steelhead	Subyearling Chinook
TDA_FB to TDA_TW (rkm 311 to 275)	0.9995 (0.0005)	0.9989 (0.0007)	0.9995 (0.0005)
TDA_TW to BON (rkm 275 to 234)	0.9950 (0.0017)	0.9972 (0.0013)	0.9461 (0.0050)
BON to BON_TW1 (rkm 234 to 153)	0.8080 (0.0095)	0.7456 (0.0106)	0.8548 (0.0080)
BON_TW1 to BON_TW2 (rkm 153 to 113)	0.9393 (0.0058)	0.9271 (0.0064)	0.9561 (0.0047)
BON_TW2 to BON_TW3 (rkm 113 to 86)	0.9480 (0.0054)	0.9418 (0.0061)	0.9347 (0.0057)

Appendix B

Tagging and Release Data

Appendix B

Tagging and Release Data

Tagging and release data are documented for yearling Chinook salmon, steelhead, and subyearling Chinook salmon in Tables B.1, B.2, and B.3, respectively.

Table B.1. 2010 Yearling Chinook Salmon Tagged at John Day Dam and Released Live at Three Sites

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
4/27/2010	4/28/2010	72	Roosevelt	72	
4/28/2010	4/29/2010	72	Roosevelt	72	
4/29/2010	4/30/2010	97	Roosevelt	72	
			TDA tailrace	25	
4/30/2010	5/1/2010	97	Roosevelt	72	
			Hood River	25	
5/1/2010	5/2/2010	147	Roosevelt	72	
			TDA tailrace[(a)]	50	
			Hood River	25	
5/2/2010	5/3/2010	96	Roosevelt	72	
			Hood River	24	
5/3/2010	5/4/2010	147	Roosevelt	72	
			TDA tailrace[(a)]	49	1
			Hood River	25	
5/4/2010	5/5/2010	103	Roosevelt	72	5[(b)]
			Hood River	26	
5/5/2010	5/6/2010	147	Roosevelt	71	1
			TDA tailrace[(a)]	50	
			Hood River	25	
5/6/2010	5/7/2010	97	Roosevelt	72	
			Hood River	25	
5/7/2010	5/8/2010	147	Roosevelt	71	1
			TDA tailrace[(a)]	49	1
			Hood River	25	
5/8/2010	5/9/2010	97	Roosevelt	72	
			Hood River	25	
5/9/2010	5/10/2010	148	Roosevelt	72	1[(b)]
			TDA tailrace[(a)]	50	
			Hood River	25	
5/10/2010	5/11/2010	23			23[(b)]
5/11/2010	5/12/2010	147	Roosevelt	72	
			TDA tailrace[(a)]	50	
			Hood River	25	

Table B.1. (contd)

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
5/12/2010	5/13/2010	194	Roosevelt	144	
			Hood River	50	
5/13/2010	5/14/2010	146	Roosevelt	72	
			TDA tailrace[(a)]	50	
			Hood River	24	
5/14/2010	5/15/2010	97	Roosevelt	72	
			Hood River	25	
5/15/2010	5/16/2010	147	Roosevelt	72	
			TDA tailrace[(a)]	50	
			Hood River	25	
5/16/2010	5/17/2010	97	Roosevelt	72	
			Hood River	25	
5/17/2010	5/18/2010	146	Roosevelt	72	
			TDA tailrace[(a)]	49	
			Hood River	25	
5/18/2010	5/19/2010	96	Roosevelt	71	
			Hood River	25	
5/19/2010	5/20/2010	147	Roosevelt	72	
			TDA tailrace[(a)]	50	
			Hood River	25	
5/20/2010	5/21/2010	97	Roosevelt	72	
			Hood River	25	
5/21/2010	5/22/2010	147	Roosevelt	72	
			TDA tailrace[(a)]	50	
			Hood River	25	
5/22/2010	5/23/2010	97	Roosevelt	72	
			Hood River	25	
5/23/2010	5/24/2010	147	Roosevelt	72	
			TDA tailrace[(a)]	50	
			Hood River	25	
5/24/2010	5/25/2010	97	Roosevelt	72	
			Hood River	25	
5/25/2010	5/26/2010	146	Roosevelt	71	
			TDA tailrace[(a)]	50	
			Hood River	25	
5/26/2010	5/27/2010	97	Roosevelt	72	
			Hood River	25	
5/27/2010	5/28/2010	147	Roosevelt	73	
			TDA tailrace[(a)]	50	
			Hood River	24	

Table B.1. (contd)

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
5/28/2010	5/29/2010	83	Roosevelt	58	
			Hood River	25	
5/29/2010	5/30/2010	75	TDA tailrace[(a)]	50	
			Hood River	25	
5/30/2010	5/31/2010	25	Hood River	25	
5/31/2010	6/1/2010	48	TDA tailrace	24	
			Hood River	24	

(a) Two releases (0800–0900 hours and 1900–2000 hours).
(b) Sacrificed to reach a goal of tagging and releasing 29 dead fish in spring.

Table B.2. 2010 Juvenile Steelhead Tagged at John Day Dam and Released Live at Three Sites

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
4/27/2010	4/28/2010	72	Roosevelt	71	1
4/28/2010	4/29/2010	72	Roosevelt	72	
4/29/2010	4/30/2010	97	Roosevelt	72	
			TDA tailrace	25	
4/30/2010	5/1/2010	97	Roosevelt	72	
			Hood River	25	
5/1/2010	5/2/2010	147	Roosevelt	72	
			TDA tailrace[a]	50	
			Hood River	25	
5/2/2010	5/3/2010	96	Roosevelt	72	
			Hood River	24	
5/3/2010	5/4/2010	150	Roosevelt	75	
			TDA tailrace[a]	49	1
			Hood River	25	
5/4/2010	5/5/2010	105	Roosevelt	71	
			Hood River	26	
					8[b]
5/5/2010	5/6/2010	147	Roosevelt	72	
			TDA tailrace[a]	50	
			Hood River	25	
5/6/2010	5/7/2010	97	Roosevelt	72	
			Hood River	25	
5/7/2010	5/8/2010	147	Roosevelt	72	
			TDA tailrace[a]	50	
			Hood River	25	
5/8/2010	5/9/2010	97	Roosevelt	72	
			Hood River	25	
5/9/2010	5/10/2010	147	Roosevelt	72	
			TDA tailrace[a]	50	
			Hood River	25	
5/10/2010	5/11/2010	27			27[b]
5/11/2010	5/12/2010	147	Roosevelt	72	
			TDA tailrace[a]	50	
			Hood River	25	
5/12/2010	5/13/2010	192	Roosevelt	142	
			Hood River	50	
5/13/2010	5/14/2010	146	Roosevelt	72	
			TDA tailrace[a]	50	
			Hood River	24	
5/14/2010	5/15/2010	97	Roosevelt	72	
			Hood River	25	

Table B.2. (contd)

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
5/15/2010	5/16/2010	146	Roosevelt	71	
			TDA tailrace[(a)]	50	
			Hood River	25	
5/16/2010	5/17/2010	97	Roosevelt	72	
			Hood River	25	
5/17/2010	5/18/2010	147	Roosevelt	72	
			TDA tailrace[(a)]	50	
			Hood River	25	
5/18/2010	5/19/2010	97	Roosevelt	72	
			Hood River	25	
5/19/2010	5/20/2010	147	Roosevelt	72	
			TDA tailrace[(a)]	50	
			Hood River	25	
5/20/2010	5/21/2010	97	Roosevelt	72	
			Hood River	25	
5/21/2010	5/22/2010	147	Roosevelt	72	
			TDA tailrace[(a)]	50	
			Hood River	25	
5/22/2010	5/23/2010	97	Roosevelt	72	
			Hood River	25	
5/23/2010	5/24/2010	147	Roosevelt	72	
			TDA tailrace[(a)]	50	
			Hood River	25	
5/24/2010	5/25/2010	97	Roosevelt	72	
			Hood River	25	
5/25/2010	5/26/2010	147	Roosevelt	72	
			TDA tailrace[(a)]	50	
			Hood River	25	
5/26/2010	5/27/2010	97	Roosevelt	72	
			Hood River	25	
5/27/2010	5/28/2010	147	Roosevelt	72	
			TDA tailrace[(a)]	50	
			Hood River	25	
5/28/2010	5/29/2010	83	Roosevelt	58	
			Hood River	25	
5/29/2010	5/30/2010	75	TDA tailrace[(a)]	50	
			Hood River	25	
5/30/2010	5/31/2010	25	Hood River	25	
5/31/2010	6/1/2010	49	TDA tailrace	25	
			Hood River	24	

(a) Two releases (0800–0900 hours and 1900–2000 hours).
(b) Sacrificed to reach a goal of tagging and releasing 35 dead fish in spring.

Table B.3. 2010 Summer Subyearling Chinook Salmon Smolts Tagged at John Day Dam and Released Live at Three Sites

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
6/12/2010	6/13/2010	89	Roosevelt	89	
6/13/2010	6/14/2010	88	Roosevelt	88	
6/14/2010	6/15/2010	114	Roosevelt	89	
			TDA tailrace	25	
6/15/2010	6/16/2010	114	Roosevelt	89	
			Hood River	25	
6/16/2010	6/17/2010	165	Roosevelt	89	
			TDA tailrace[(a)]	50	
			Hood River	25	
					1[(b)]
6/17/2010	6/18/2010	114	Roosevelt	89	
			Hood River	24	1
6/18/2010	6/19/2010	177	Roosevelt	88	1
			TDA tailrace[(a)]	50	
			Hood River	25	
					13[(b)]
6/19/2010	6/20/2010	114	Roosevelt	89	
			Hood River	25	
6/20/2010	6/21/2010	164	Roosevelt	89	
			TDA tailrace[(a)]	50	
			Hood River	25	
6/21/2010	6/22/2010	113	Roosevelt	89	
			Hood River	24	
6/22/2010	6/23/2010	164	Roosevelt	89	
			TDA tailrace[(a)]	50	
			Hood River	25	
6/23/2010	6/24/2010	115	Roosevelt	89	
			Hood River	26	
6/24/2010	6/25/2010	135	Roosevelt	75	
			TDA tailrace[(a)]	40	
			Hood River	20	
6/25/2010	6/26/2010	128	Roosevelt	89	
			Hood River	25	
					14[(b)]
6/26/2010	6/27/2010	162	Roosevelt	89	
			TDA tailrace[(a)]	50	
			Hood River	23	
6/27/2010	6/28/2010	116	Roosevelt	90	
			Hood River	25	1

Table B.3. (contd)

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
6/28/2010	6/29/2010	165	Roosevelt	90	
			TDA tailrace[(a)]	49	1
			Hood River	24	1
6/29/2010	6/30/2010	114	Roosevelt	89	
			Hood River	25	
6/30/2010	7/1/2010	193	Roosevelt	103	
			TDA tailrace[(a)]	60	
			Hood River	30	
7/1/2010	7/2/2010	113	Roosevelt	89	
			Hood River	23	1
7/2/2010	7/3/2010	164	Roosevelt	89	
			TDA tailrace[(a)]	50	
			Hood River	25	
7/3/2010	7/4/2010	114	Roosevelt	89	
			Hood River	25	
7/4/2010	7/5/2010	164	Roosevelt	89	
			TDA tailrace[(a)]	50	
			Hood River	25	
7/5/2010	7/6/2010	125	Roosevelt	88	1
			Hood River	25	
					11[(b)]
7/6/2010	7/7/2010	164	Roosevelt	89	
			TDA tailrace[(a)]	50	
			Hood River	25	
7/7/2010	7/8/2010	114	Roosevelt	89	
			Hood River	25	
7/8/2010	7/9/2010	163	Roosevelt	88	
			TDA tailrace[(a)]	49	1
			Hood River	25	
7/9/2010	7/10/2010	129	Roosevelt	89	
			Hood River	25	
					15[(b)]
7/10/2010	7/11/2010	163	Roosevelt	89	
			TDA tailrace[(a)]	50	
			Hood River	23	1
7/11/2010	7/12/2010	115	Roosevelt	90	
			Hood River	24	1
7/12/2010	7/13/2010	166	Roosevelt	90	
			TDA tailrace[(a)]	50	
			Hood River	25	
					1[(b)]

Table B.3. (contd)

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
7/13/2010	7/14/2010	115	Roosevelt	90	
			Hood River	25	
7/14/2010	7/15/2010	82	TDA tailrace[(a)]	52	
			Hood River	30	
7/15/2010	7/16/2010	31	Hood River	29	
					2[(b)]
7/16/2010	7/17/2010	50	TDA tailrace[(a)]	25	
			Hood River	25	

(a) Two releases (0800–0900 hours and 1900–2000 hours)
(b) Sacrificed to reach a goal of tagging and releasing 57 dead fish in spring.

Appendix C

Hydrophone Deployment Locations

Appendix C

Hydrophone Deployment Locations

Deployment locations for hydrophones in dam-face arrays for 2010 The Dalles Dam survival study are presented in Table C.1. GPS locations for the nodes in the autonomous arrays are listed in Table C.2.

Table C.1. Hydrophone Locations in The Dalles Dam-Faced Array in 2010

HYDROPHONE NAME	Latitude (NAD83)	Longitude (NAD83)	Elevation (NAVD88, ft.)
Fu 0_1_S	45.6158073	-121.1273525	150.21
Fu 0_1_D	45.6158228	-121.1273741	109.39
FU1_FU2_S	45.6158840	-121.1272402	150.17
FU1_FU2_D	45.6158995	-121.1272619	109.35
FU2_MU1_S	45.6159637	-121.1271233	149.94
FU2_MU1_D	45.6159793	-121.1271449	109.12
MU1_MU2_S	45.6161352	-121.1268723	151.01
MU1_MU2_D	45.6161508	-121.1268939	110.19
MU2_3_S	45.6162983	-121.1266337	151.08
MU2_3_D	45.6163139	-121.1266553	110.26
MU3_4_S	45.6164632	-121.1263926	151.23
MU3_4_D	45.6164788	-121.1264143	110.41
MU4_5_S	45.6166281	-121.1261515	151.10
MU4_5_D	45.6166437	-121.1261731	110.28
MU5_6_S	45.6167887	-121.1259159	151.06
MU5_6_D	45.6168043	-121.1259375	110.24
MU6_7_S	45.6169538	-121.1256758	151.16
MU6_7_D	45.6169694	-121.1256974	110.34
MU 7_8_S	45.6171185	-121.1254349	151.08
MU7_8_D	45.6171341	-121.1254565	110.26
MU8_SS_S	45.6172801	-121.1251917	154.87
SS_MU9_S	45.6174459	-121.1249499	154.89
MU9_10_S	45.6176129	-121.1247124	150.85
MU9_10_D	45.6176285	-121.1247341	110.03
MU10_11_S	45.6177770	-121.1244719	151.50
MU10_11_D	45.6177926	-121.1244936	110.68
MU11_12_S	45.6179410	-121.1242328	151.61
MU11_12_D	45.6179565	-121.1242544	110.79
MU12_13_S	45.6181069	-121.1239915	151.04
MU12_13_D	45.6181224	-121.1240132	110.22
MU13_14_S	45.6182718	-121.1237509	151.39
MU13_14_D	45.6182874	-121.1237726	110.57
MU14_15_S	45.6184358	-121.1235096	151.40
MU14_15_D	45.6184514	-121.1235312	110.58
MU15_16_S	45.6186007	-121.1232687	151.29

Table C.1. (contd)

HYDROPHONE NAME	Latitude (NAD83)	Longitude (NAD83)	Elevation (NAVD88, ft.)
MU15_16_D	45.6186163	-121.1232904	110.47
MU16_17_S	45.6187658	-121.1230280	151.39
MU16_17_D	45.6187814	-121.1230497	110.57
MU17_18_S	45.6189303	-121.1227876	151.58
MU17_18_D	45.6189459	-121.1228092	110.76
MU18_19_S	45.6190950	-121.1225468	151.32
MU18_19_D	45.6191106	-121.1225685	110.50
MU19_20_S	45.6192590	-121.1223070	151.26
MU19_20_D	45.6192746	-121.1223286	110.44
MU20_21_S	45.6194241	-121.1220655	151.12
MU20_21_D	45.6194397	-121.1220872	110.30
MU21_22_S	45.6195887	-121.1218258	151.18
MU21_22_D	45.6196043	-121.1218474	110.36
MU22_0_S	45.6197495	-121.1215899	151.16
MU22_0_D	45.6197650	-121.1216116	110.34
N1_S	45.6153492	-121.1365173	146.66
N2_S	45.6152700	-121.1363622	146.64
N3_S	45.6150256	-121.1359571	146.28
N4_S	45.6149133	-121.1357392	146.15
S0_1_S	45.6147994	-121.1355107	154.50
S0_1_D	45.6147994	-121.1355107	126.83
S1_2_S	45.6147056	-121.1353252	154.28
S1_2_D	45.6147056	-121.1353252	126.53
S2_3_S	45.6146099	-121.1351377	154.10
S2_3_D	45.6146099	-121.1351377	126.52
S3_4_S	45.6145115	-121.1349452	154.26
S3_4_D	45.6145115	-121.1349452	126.59
S4_5_S	45.6144155	-121.1347571	154.35
S4_5_D	45.6144155	-121.1347571	126.76
S5_6_S	45.6143184	-121.1345675	154.23
S5_6_D	45.6143184	-121.1345675	126.65
S6_7_S	45.6142215	-121.1343775	154.34
S6_7_D	45.6142215	-121.1343775	126.67
S7_8_S	45.6141251	-121.1341883	154.48
S7_8_D	45.6141251	-121.1341883	126.73
S8_9_S	45.6140275	-121.1339980	154.38
S8_9_D	45.6140275	-121.1339980	126.63
S9_10_S	45.6139311	-121.1338095	154.27
S9_10_D	45.6139311	-121.1338095	126.68
S10_11_S	45.6138335	-121.1336189	154.36
S10_11_D	45.6138335	-121.1336189	126.69
S11_12_S	45.6137372	-121.1334299	154.28
S11_12_D	45.6137372	-121.1334299	126.61
S12_13_S	45.6136409	-121.1332412	154.34
S12_13_D	45.6136409	-121.1332412	126.75

Table C.2. Approximate Global Positioning System Coordinates of Autonomous Nodes Deployed in Arrays Just Above and Below The Dalles Dam in 2010. Array_Node is a concatenation of an array name and an autonomous node number. The array name starts with "CR" for Columbia River, with a three-digit number corresponding to river kilometer upstream of the mouth of the Columbia River. Nodes within an array are numbered from the Washington to the Oregon shore.

Array_Node	Array Function	Latitude Degrees North	Longitude Degrees West
CR311.0_01	TDA Forebay	45.628109	-121.1145674
CR311.0_02		45.627521	-121.1136422
CR311.0_03		45.626945	-121.112629
CR311.0_04		45.626495	-121.1117558
CR311.0_05		45.626036	-121.1108816
CR307.0_01	TDA Egress	45.608316	-121.151094
CR307.0_02		45.607285	-121.150035
CR307.0_03		45.60637584	-121.1488432
CR275.0_01	TDA Tailwater	45.70912592	-121.471297
CR275.0_02		45.70862232	-121.4717591
CR275.0_03		45.707833	-121.47244
CR275.0_04		45.7072916	-121.4729401
CR275.0_05		45.706644	-121.4735049
CR275.0_06		45.70576676	-121.4734668
CR236.0_01	BON Forebay	45.650974	-121.9203458
CR236.0_02		45.650435	-121.9198846
CR236.0_03		45.6498599	-121.9193208
CR236.0_04		45.6493209	-121.9188596
CR233.0_01	BON Egress	45.6350168	-121.9624832
CR233.0_02		45.635027	-121.9613769
CR233.0_03		45.6346313	-121.960605
CR153.0_01	BON Primary	45.7449562	-122.7858224
CR153.0_02		45.7445609	-122.7660408
CR153.0_03		45.7465749	-122.7629473
CR153.0_04		45.7452083	-122.763715
CR153.0_05		45.7441297	-122.7652561
CR113.0_01	BON Secondary	46.0633259	-122.8693984
CR113.0_02		46.0707306	-122.8868271
CR113.0_03		46.0699943	-122.8872084
CR113.0_04		46.0693229	-122.8888071
CR113.0_05		46.0694009	-122.8900944
CR113.0_06		46.0711953	-122.8919111
CR113.0_07		46.0687756	-122.8902994
CR113.0_08		46.0691116	-122.8916534
CR113.0_09		46.0684816	-122.8922447
CR113.0_10		46.0689276	-122.8939764
CR086.2_01	BON Tertiary	46.1860936	-123.1806843

Table C.2. (contd)

Array_Node	Array Function	Latitude Degrees North	Longitude Degrees West
CR086.2_02		46.1859806	-123.179256
CR086.2_03		46.1849006	-123.180578
CR086.2_04		46.1841513	-123.178923
CR086.2_05		46.1840586	-123.1778617
CR086.2_06		46.1834166	-123.1784803

Appendix D

Capture-History Data

Appendix D

Capture-History Data

Capture histories are presented for yearling Chinook salmon (Tables D.1 and D.2), steelhead (Table D.3 and D.4), and subyearling Chinook salmon (Tables D.5 and D.6).

Table D.1. Capture Histories at Sites D_1–D_6 (Figure 2.1) for Release Group V_1 for Yearling Chinook Salmon Used in Estimating Dam Passage Survival and Forebay-to-Tailrace Survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival
1 1 1 1 1 1:	1219	1219
0 1 1 1 1 1:	1	1
1 0 1 1 1 1:	4	4
0 0 1 1 1 1:	0	0
1 1 0 1 1 1:	270	270
0 1 0 1 1 1:	0	0
1 0 0 1 1 1:	3	3
0 0 0 1 1 1:	0	0
1 1 1 0 1 1:	67	67
0 1 1 0 1 1:	0	0
1 0 1 0 1 1:	1	1
0 0 1 0 1 1:	0	0
1 1 0 0 1 1:	21	21
0 1 0 0 1 1:	0	0
1 0 0 0 1 1:	0	0
0 0 0 0 1 1:	0	0
1 1 1 1 0 1:	55	55
0 1 1 1 0 1:	0	0
1 0 1 1 0 1:	0	0
0 0 1 1 0 1:	0	0
1 1 0 1 0 1:	19	19
0 1 0 1 0 1:	0	0
1 0 0 1 0 1:	0	0
0 0 0 1 0 1:	0	0
1 1 1 0 0 1:	9	9
0 1 1 0 0 1:	0	0
1 0 1 0 0 1:	0	0
0 0 1 0 0 1:	0	0

Table D.1. (contd)

	V_1	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival
1 1 0 0 0 1:	4	4
0 1 0 0 0 1:	0	0
1 0 0 0 0 1:	0	0
0 0 0 0 0 1:	0	0
1 1 1 1 2 0:	0	0
0 1 1 1 2 0:	0	0
1 0 1 1 2 0:	0	0
0 0 1 1 2 0:	0	0
1 1 0 1 2 0:	0	0
0 1 0 1 2 0:	0	0
1 0 0 1 2 0:	0	0
0 0 0 1 2 0:	0	0
1 1 1 0 2 0:	0	0
0 1 1 0 2 0:	0	0
1 0 1 0 2 0:	0	0
0 0 1 0 2 0:	0	0
1 1 0 0 2 0:	0	0
0 1 0 0 2 0:	0	0
1 0 0 0 2 0:	0	0
0 0 0 0 2 0:	0	0
1 1 1 1 1 0:	28	28
0 1 1 1 1 0:	0	0
1 0 1 1 1 0:	1	1
0 0 1 1 1 0:	0	0
1 1 0 1 1 0:	8	8
0 1 0 1 1 0:	0	0
1 0 0 1 1 0:	0	0
0 0 0 1 1 0:	0	0
1 1 1 0 1 0:	1	1
0 1 1 0 1 0:	0	0
1 0 1 0 1 0:	0	0
0 0 1 0 1 0:	0	0
1 1 0 0 1 0:	1	1
0 1 0 0 1 0:	0	0
1 0 0 0 1 0:	0	0
0 0 0 0 1 0:	0	0
1 1 1 2 0 0:	0	0
0 1 1 2 0 0:	0	0
1 0 1 2 0 0:	0	0
0 0 1 2 0 0:	0	0
1 1 0 2 0 0:	0	0

Table D.1. (contd)

	V_1	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival
0 1 0 2 0 0:	0	0
1 0 0 2 0 0:	0	0
0 0 0 2 0 0:	0	0
1 1 1 1 0 0:	7	7
0 1 1 1 0 0:	0	0
1 0 1 1 0 0:	0	0
0 0 1 1 0 0:	0	0
1 1 0 1 0 0:	5	5
0 1 0 1 0 0:	0	0
1 0 0 1 0 0:	0	0
0 0 0 1 0 0:	0	0
1 1 2 0 0 0:	0	0
0 1 2 0 0 0:	0	0
1 0 2 0 0 0:	0	0
0 0 2 0 0 0:	0	0
1 1 1 0 0 0:	11	11
0 1 1 0 0 0:	0	0
1 0 1 0 0 0:	0	0
0 0 1 0 0 0:	0	0
1 2 0 0 0 0:	57	57
0 2 0 0 0 0:	0	0
1 1 0 0 0 0:	88	88
0 1 0 0 0 0:	0	0
2 0 0 0 0 0:	0	0
1 0 0 0 0 0:	34	34
0 0 0 0 0 0:	123	125
Total	**2,037**	**2,039**

Table D.2. Capture Histories at Sites D_1–D_6 (Figure 2.1) for Release Groups R_2, and R_3 for Yearling Chinook Salmon Used in Estimating Dam Passage Survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	Dam Passage Survival	
Capture History	R_2	R_3
1 1 1 1 1:	503	503
0 1 1 1 1:	4	2
1 0 1 1 1:	119	121
0 0 1 1 1:	0	0
1 1 0 1 1:	35	37
0 1 0 1 1:	0	0
1 0 0 1 1:	8	12
0 0 0 1 1:	0	0
1 1 1 0 1:	24	31
0 1 1 0 1:	0	0
1 0 1 0 1:	8	11
0 0 1 0 1:	0	0
1 1 0 0 1:	1	2
0 1 0 0 1:	0	0
1 0 0 0 1:	0	0
0 0 0 0 1:	0	0
1 1 1 2 0:	0	0
0 1 1 2 0:	0	0
1 0 1 2 0:	0	0
0 0 1 2 0:	0	0
1 1 0 2 0:	0	0
0 1 0 2 0:	0	0
1 0 0 2 0:	0	0
0 0 0 2 0:	0	0
1 1 1 1 0:	7	17
0 1 1 1 0:	0	0
1 0 1 1 0:	4	3
0 0 1 1 0:	0	0
1 1 0 1 0:	0	1
0 1 0 1 0:	0	0
1 0 0 1 0:	1	1
0 0 0 1 0:	0	0
1 1 2 0 0:	0	0
0 1 2 0 0:	0	0
1 0 2 0 0:	0	0
0 0 2 0 0:	0	0
1 1 1 0 0:	3	1
0 1 1 0 0:	0	0

Table D.2. (contd)

	Dam Passage Survival	
Capture History	R_2	R_3
1 0 1 0 0:	2	3
0 0 1 0 0:	0	0
1 2 0 0 0:	0	0
0 2 0 0 0:	0	0
1 1 0 0 0:	1	3
0 1 0 0 0:	0	0
2 0 0 0 0:	0	1
1 0 0 0 0:	45	37
0 0 0 0 0:	31	11
Total	**796**	**797**

Table D.3. Capture Histories at Sites D_1–D_6 (Figure 2.1) for Release Group V_1 for Steelhead Used in Estimating Dam Passage Survival and Forebay-to-Tailrace Survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival
1 1 1 1 1 1:	997	996
0 1 1 1 1 1:	0	0
1 0 1 1 1 1:	1	1
0 0 1 1 1 1:	0	0
1 1 0 1 1 1:	318	318
0 1 0 1 1 1:	0	0
1 0 0 1 1 1:	0	0
0 0 0 1 1 1:	0	0
1 1 1 0 1 1:	58	58
0 1 1 0 1 1:	0	0
1 0 1 0 1 1:	1	1
0 0 1 0 1 1:	0	0
1 1 0 0 1 1:	32	32
0 1 0 0 1 1:	0	0
1 0 0 0 1 1:	1	1
0 0 0 0 1 1:	0	0
1 1 1 1 0 1:	62	62
0 1 1 1 0 1:	0	0
1 0 1 1 0 1:	0	0
0 0 1 1 0 1:	0	0
1 1 0 1 0 1:	18	18
0 1 0 1 0 1:	0	0
1 0 0 1 0 1:	0	0
0 0 0 1 0 1:	0	0
1 1 1 0 0 1:	2	2
0 1 1 0 0 1:	0	0
1 0 1 0 0 1:	0	0
0 0 1 0 0 1:	0	0
1 1 0 0 0 1:	5	5
0 1 0 0 0 1:	0	0
1 0 0 0 0 1:	0	0
0 0 0 0 0 1:	0	0
1 1 1 1 2 0:	0	0
0 1 1 1 2 0:	0	0
1 0 1 1 2 0:	0	0
0 0 1 1 2 0:	0	0
1 1 0 1 2 0:	0	0
0 1 0 1 2 0:	0	0

Table D.3. (contd)

	V_1	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival
1 0 0 1 2 0:	0	0
0 0 0 1 2 0:	0	0
1 1 1 0 2 0:	0	0
0 1 1 0 2 0:	0	0
1 0 1 0 2 0:	0	0
0 0 1 0 2 0:	0	0
1 1 0 0 2 0:	0	0
0 1 0 0 2 0:	0	0
1 0 0 0 2 0:	0	0
0 0 0 0 2 0:	0	0
1 1 1 1 1 0:	103	103
0 1 1 1 1 0:	0	0
1 0 1 1 1 0:	1	1
0 0 1 1 1 0:	0	0
1 1 0 1 1 0:	40	40
0 1 0 1 1 0:	0	0
1 0 0 1 1 0:	0	0
0 0 0 1 1 0:	0	0
1 1 1 0 1 0:	12	12
0 1 1 0 1 0:	0	0
1 0 1 0 1 0:	0	0
0 0 1 0 1 0:	0	0
1 1 0 0 1 0:	10	10
0 1 0 0 1 0:	0	0
1 0 0 0 1 0:	0	0
0 0 0 0 1 0:	0	0
1 1 1 2 0 0:	0	0
0 1 1 2 0 0:	0	0
1 0 1 2 0 0:	0	0
0 0 1 2 0 0:	0	0
1 1 0 2 0 0:	0	0
0 1 0 2 0 0:	0	0
1 0 0 2 0 0:	0	0
0 0 0 2 0 0:	0	0
1 1 1 1 0 0:	23	23
0 1 1 1 0 0:	0	0
1 0 1 1 0 0:	1	1
0 0 1 1 0 0:	0	0
1 1 0 1 0 0:	6	6
0 1 0 1 0 0:	0	0
1 0 0 1 0 0:	0	0

Table D.3. (contd)

Capture History	V_1 Dam Passage Survival	V_1 BRZ-to-BRZ Survival
0 0 0 1 0 0:	0	0
1 1 2 0 0 0:	0	0
0 1 2 0 0 0:	0	0
1 0 2 0 0 0:	0	0
0 0 2 0 0 0:	0	0
1 1 1 0 0 0:	21	21
0 1 1 0 0 0:	0	0
1 0 1 0 0 0:	0	0
0 0 1 0 0 0:	0	0
1 2 0 0 0 0:	68	68
0 2 0 0 0 0:	0	0
1 1 0 0 0 0:	118	118
0 1 0 0 0 0:	3	2
2 0 0 0 0 0:	0	0
1 0 0 0 0 0:	48	49
0 0 0 0 0 0:	99	101
Total	**2,048**	**2,049**

Table D.4. Capture Histories at Sites D_1–D_6 (Figure 2.1) for Release Groups R_2, and R_3 for Steelhead Used in Estimating Dam Passage Survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	Dam Passage Survival	
Capture History	R_2	R_3
1 1 1 1 1:	456	436
0 1 1 1 1:	0	2
1 0 1 1 1:	132	124
0 0 1 1 1:	0	0
1 1 0 1 1:	31	30
0 1 0 1 1:	0	0
1 0 0 1 1:	13	16
0 0 0 1 1:	0	0
1 1 1 0 1:	23	30
0 1 1 0 1:	0	0
1 0 1 0 1:	8	8
0 0 1 0 1:	0	0
1 1 0 0 1:	2	2
0 1 0 0 1:	0	0
1 0 0 0 1:	1	3
0 0 0 0 1:	0	1
1 1 1 2 0:	0	0
0 1 1 2 0:	0	0
1 0 1 2 0:	0	0
0 0 1 2 0:	0	0
1 1 0 2 0:	0	0
0 1 0 2 0:	0	0
1 0 0 2 0:	0	0
0 0 0 2 0:	0	0
1 1 1 1 0:	49	48
0 1 1 1 0:	0	0
1 0 1 1 0:	8	20
0 0 1 1 0:	1	0
1 1 0 1 0:	4	5
0 1 0 1 0:	0	0
1 0 0 1 0:	0	1
0 0 0 1 0:	0	0
1 1 2 0 0:	0	0
0 1 2 0 0:	0	0
1 0 2 0 0:	0	0
0 0 2 0 0:	0	0
1 1 1 0 0:	6	4
0 1 1 0 0:	0	0

Table D.4. (contd)

	Dam Passage Survival	
Capture History	R_2	R_3
1 0 1 0 0:	0	1
0 0 1 0 0:	0	0
1 2 0 0 0:	0	0
0 2 0 0 0:	0	0
1 1 0 0 0:	6	3
0 1 0 0 0:	0	0
2 0 0 0 0:	0	0
1 0 0 0 0:	34	40
0 0 0 0 0:	25	24
Total	**799**	**798**

Table D.5. Capture Histories at Sites D_1–D_6 (Figure 2.1) for Release Group V_1 for Subyearling Chinook Salmon Used in Estimating Dam Passage Survival and Forebay-to-Tailrace Survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival
1 1 1 1 1 1:	1365	1361
0 1 1 1 1 1:	0	0
1 0 1 1 1 1:	86	86
0 0 1 1 1 1:	0	0
1 1 0 1 1 1:	226	226
0 1 0 1 1 1:	0	0
1 0 0 1 1 1:	10	10
0 0 0 1 1 1:	0	0
1 1 1 0 1 1:	66	66
0 1 1 0 1 1:	0	0
1 0 1 0 1 1:	2	2
0 0 1 0 1 1:	0	0
1 1 0 0 1 1:	11	11
0 1 0 0 1 1:	0	0
1 0 0 0 1 1:	0	0
0 0 0 0 1 1:	0	0
1 1 1 1 0 1:	83	83
0 1 1 1 0 1:	1	1
1 0 1 1 0 1:	4	4
0 0 1 1 0 1:	0	0
1 1 0 1 0 1:	30	30
0 1 0 1 0 1:	0	0
1 0 0 1 0 1:	0	0
0 0 0 1 0 1:	0	0
1 1 1 0 0 1:	5	5
0 1 1 0 0 1:	0	0
1 0 1 0 0 1:	0	0
0 0 1 0 0 1:	0	0
1 1 0 0 0 1:	0	0
0 1 0 0 0 1:	0	0
1 0 0 0 0 1:	0	0
0 0 0 0 0 1:	0	0
1 1 1 1 2 0:	0	0
0 1 1 1 2 0:	0	0
1 0 1 1 2 0:	0	0
0 0 1 1 2 0:	0	0
1 1 0 1 2 0:	0	0

Table D.5. (contd)

	V_1	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival
0 1 0 1 2 0:	0	0
1 0 0 1 2 0:	0	0
0 0 0 1 2 0:	0	0
1 1 1 0 2 0:	0	0
0 1 1 0 2 0:	0	0
1 0 1 0 2 0:	0	0
0 0 1 0 2 0:	0	0
1 1 0 0 2 0:	0	0
0 1 0 0 2 0:	0	0
1 0 0 0 2 0:	0	0
0 0 0 0 2 0:	0	0
1 1 1 1 1 0:	41	41
0 1 1 1 1 0:	0	0
1 0 1 1 1 0:	3	3
0 0 1 1 1 0:	0	0
1 1 0 1 1 0:	6	6
0 1 0 1 1 0:	0	0
1 0 0 1 1 0:	0	0
0 0 0 1 1 0:	0	0
1 1 1 0 1 0:	1	1
0 1 1 0 1 0:	0	0
1 0 1 0 1 0:	0	0
0 0 1 0 1 0:	0	0
1 1 0 0 1 0:	0	0
0 1 0 0 1 0:	0	0
1 0 0 0 1 0:	0	0
0 0 0 0 1 0:	0	0
1 1 1 2 0 0:	0	0
0 1 1 2 0 0:	0	0
1 0 1 2 0 0:	0	0
0 0 1 2 0 0:	0	0
1 1 0 2 0 0:	0	0
0 1 0 2 0 0:	0	0
1 0 0 2 0 0:	0	0
0 0 0 2 0 0:	0	0
1 1 1 1 0 0:	22	22
0 1 1 1 0 0:	0	0
1 0 1 1 0 0:	3	3
0 0 1 1 0 0:	0	0
1 1 0 1 0 0:	2	2
0 1 0 1 0 0:	0	0

Table D.5. (contd)

	V_1	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival
1 0 0 1 0 0:	0	0
0 0 0 1 0 0:	0	0
1 1 2 0 0 0:	0	0
0 1 2 0 0 0:	0	0
1 0 2 0 0 0:	0	0
0 0 2 0 0 0:	0	0
1 1 1 0 0 0:	32	31
0 1 1 0 0 0:	0	0
1 0 1 0 0 0:	1	1
0 0 1 0 0 0:	0	0
1 2 0 0 0 0:	31	31
0 2 0 0 0 0:	0	0
1 1 0 0 0 0:	141	141
0 1 0 0 0 0:	0	0
2 0 0 0 0 0:	0	0
1 0 0 0 0 0:	54	54
0 0 0 0 0 0:	191	203
Total	**2,417**	**2,424**

Table D.6. Capture Histories at Sites D_1–D_6 (Figure 2.1) for Release Groups R_2, and R_3 for Subyearling Chinook Salmon Used in Estimating Dam Passage Survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	Dam Passage Survival	
Capture History	R_2	R_3
1 1 1 1 1:	493	505
0 1 1 1 1:	38	47
1 0 1 1 1:	86	71
0 0 1 1 1:	6	9
1 1 0 1 1:	24	25
0 1 0 1 1:	4	2
1 0 0 1 1:	4	4
0 0 0 1 1:	0	1
1 1 1 0 1:	28	37
0 1 1 0 1:	0	2
1 0 1 0 1:	5	4
0 0 1 0 1:	0	2
1 1 0 0 1:	1	1
0 1 0 0 1:	0	0
1 0 0 0 1:	0	0
0 0 0 0 1:	0	0
1 1 1 2 0:	0	0
0 1 1 2 0:	0	0
1 0 1 2 0:	0	0
0 0 1 2 0:	0	0
1 1 0 2 0:	0	0
0 1 0 2 0:	0	0
1 0 0 2 0:	0	0
0 0 0 2 0:	0	0
1 1 1 1 0:	20	26
0 1 1 1 0:	2	1
1 0 1 1 0:	1	2
0 0 1 1 0:	0	0
1 1 0 1 0:	3	0
0 1 0 1 0:	0	0
1 0 0 1 0:	0	0
0 0 0 1 0:	0	1
1 1 2 0 0:	0	0
0 1 2 0 0:	0	0
1 0 2 0 0:	0	0
0 0 2 0 0:	0	0
1 1 1 0 0:	16	5
0 1 1 0 0:	2	1

Table D.6. (contd)

	Dam Passage Survival	
Capture History	R_2	R_3
1 0 1 0 0:	0	1
0 0 1 0 0:	1	0
1 2 0 0 0:	0	0
0 2 0 0 0:	0	0
1 1 0 0 0:	6	11
0 1 0 0 0:	1	0
2 0 0 0 0:	0	1
1 0 0 0 0:	33	31
0 0 0 0 0:	26	10
Total	**800**	**800**

Appendix E

Assessment of Survival Model Assumptions

Appendix E

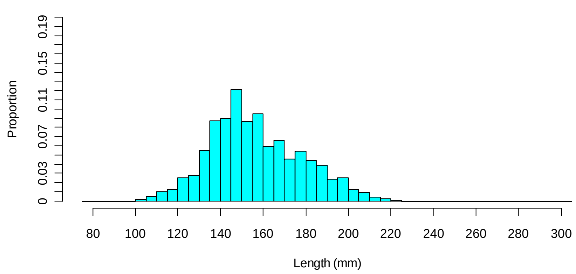
Assessment of Survival Model Assumptions

The assessment of assumptions covers fish size distribution, handling mortality and tag shedding, tag-life corrections, arrival distributions, downstream mixing, and tagger effects.

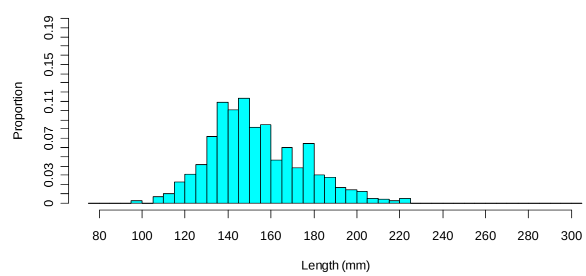
E.1 Fish Size Distribution

Comparison of acoustically tagged fish with run-of-river (ROR) fish sampled at John Day Dam through the Smolt Monitoring Program shows that the length frequency distributions were generally well matched for yearling Chinook salmon (Figure E.1), steelhead (Figure E.2), and subyearling Chinook salmon (Figure E.3). For steelhead, the upper size limit for the tagged fish was truncated with none of the very large fish (>260 mm) being tagged. The length distributions for the three yearling Chinook salmon releases (Figure E.1) and the three steelhead releases (Figure E.2) were quite similar. The median length for acoustically tagged yearling Chinook salmon was 153 mm. For steelhead smolts, the median length of the tagged fish was 214 mm. the median length per release for yearling Chinook salmon decreased by about 25 mm from ~170 mm to ~145 mm as the spring season progressed, while median length per release for steelhead was uniform throughout the study (Figures E.1 and E2).

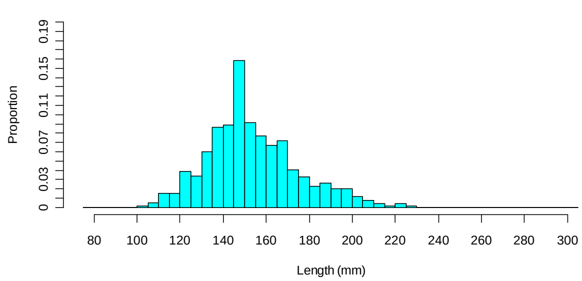
a. The Dalles Dam (Release V_1)



b. The Dalles Tailrace (Release R_2)



c. Hood River (Release R_3)



d. ROR Yearling Chinook at John Day

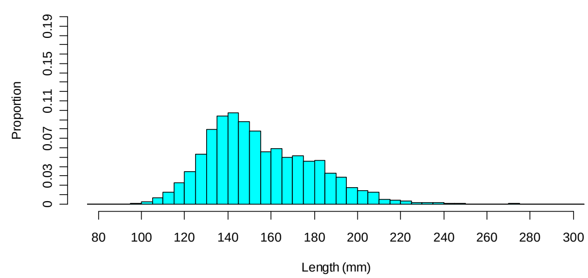


Figure E.1. Relative Frequency Distributions for Fish Length (mm) of Yearling Chinook Salmon Smolts Used in a) Release V_1, b) Release R_2, c) Release R_3, and d) ROR Fish Sampled at John Day Dam for the Smolt Monitoring Program

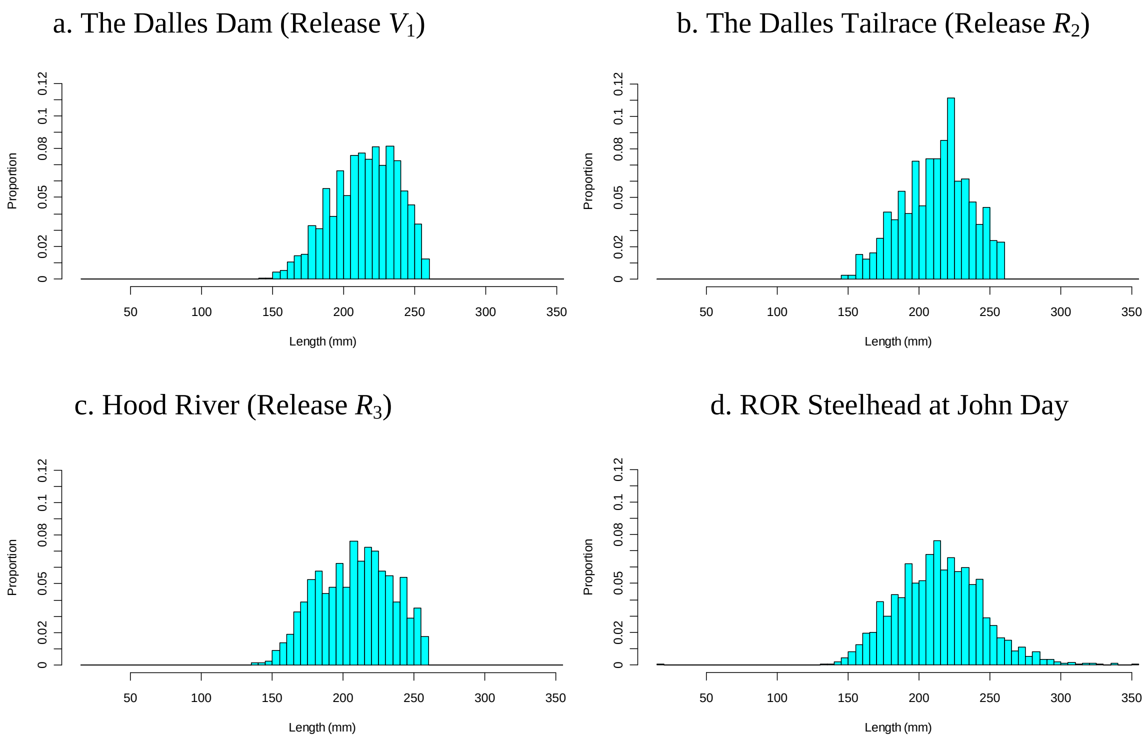


Figure E.2. Relative Frequency Distributions for Fish Length (mm) of Steelhead Smolts Used in (a) Release V_1, (b) Release R_2, (c) Release R_3, and (d) ROR Fish Sampled at John Day Dam for the Smolt Monitoring Program

Tagged subyearling Chinook salmon had less representation in the 95- to 100-mm and 105-to 110-mm categories than the ROR fish. No fish below 95 mm were tagged. The length distributions for the three subyearling Chinook salmon releases (Figure E.3) were quite similar. The median length for acoustically tagged subyearling Chinook salmon was 110 mm. The median length of subyearling Chinook salmon tagged across the course of the study remained stable over time (Figure E.4).

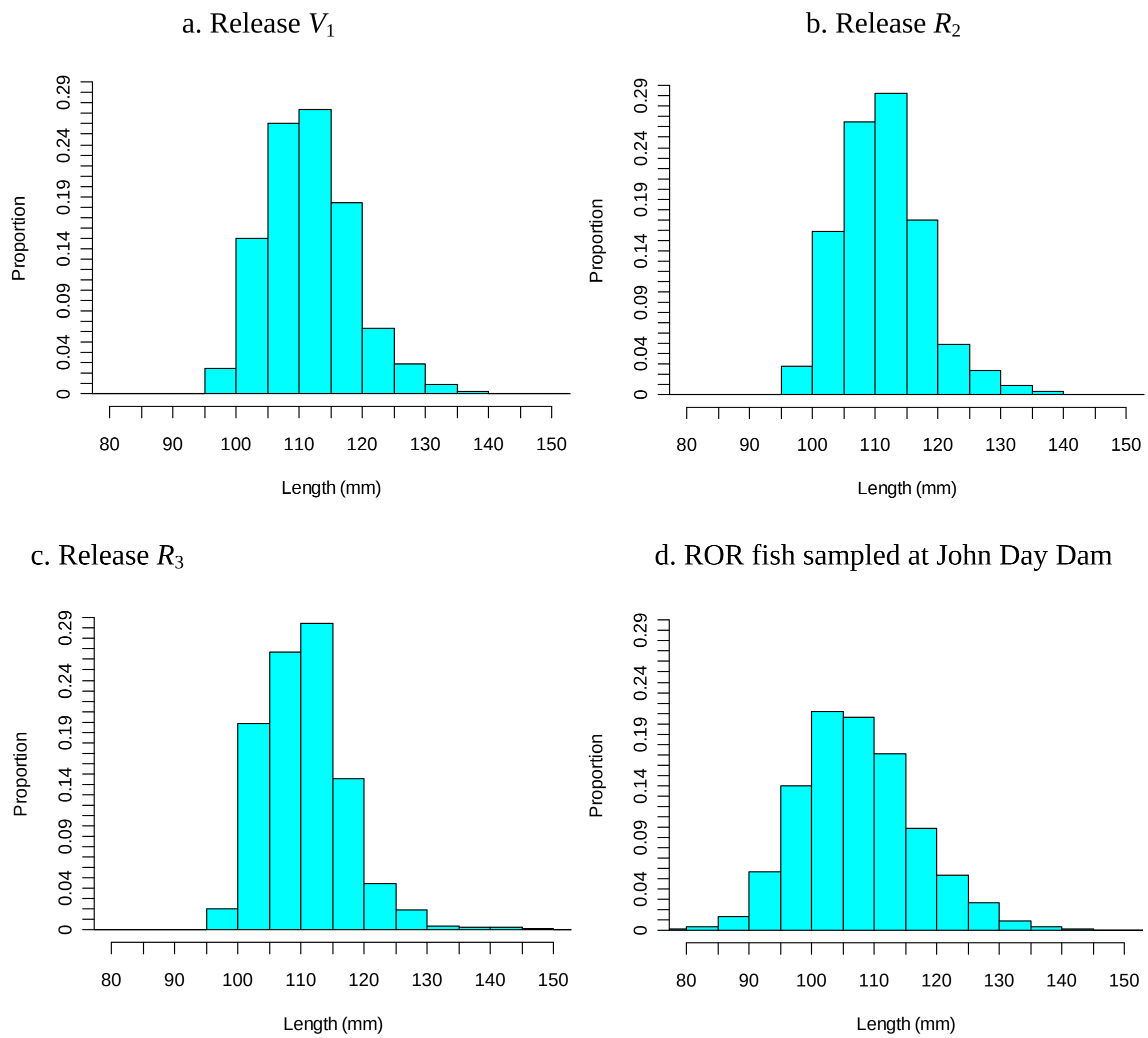
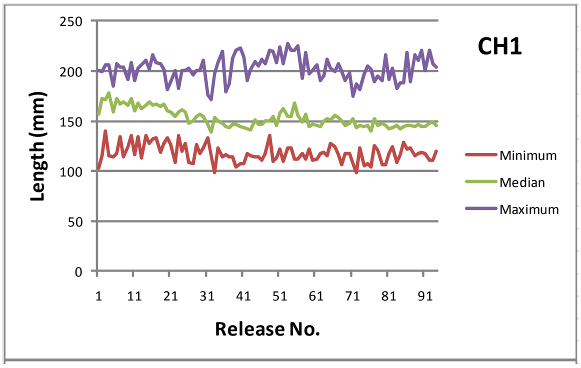
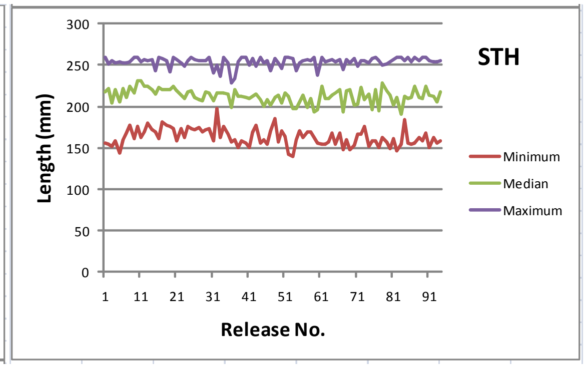


Figure E.3. Relative Frequency Distributions for Fish Length (mm) of Subyearling Chinook Salmon Smolts Used in a) Release V_1, b) Release R_2, c) Release R_3, and d) ROR Fish Sampled at John Day Dam for the Smolt Monitoring Program

a. Yearling Chinook Salmon



b. Steelhead



c. Subyearling Chinook Salmon

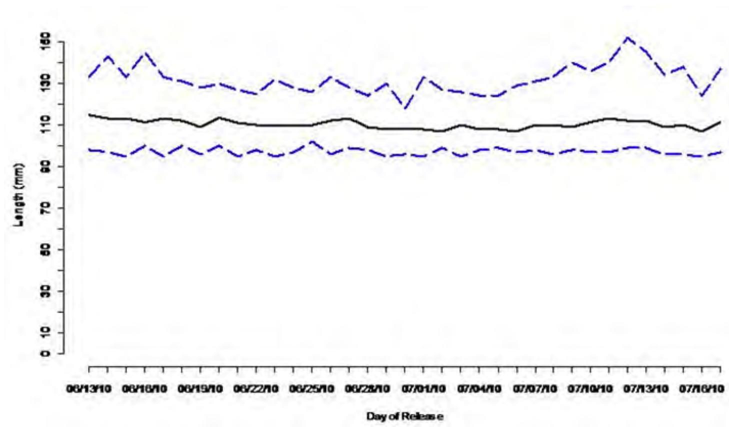


Figure E.4. Range and Median Lengths of Acoustically Tagged Yearling Chinook Salmon, Steelhead, and Subyearling Chinook Salmon Used in the 2010 Survival Studies

E.2 Handling Mortality and Tag Shedding

Fish were held for 24 h prior to release. The 24-h tagging mortality in spring was 0.20%. No tags were shed during the 24-h holding period.

E.3 Tag-Life Corrections

For the spring 2010 study, mean tag life (n = 49) was 32.73 d. The earliest tag failure was at 7.8 d and the latest at 39.6 d. The failure-time data for the acoustic tags was fit to a four-parameter vitality model of Li and Anderson (2009). The maximum likelihood estimates for the four model parameters were $\hat{r} = 0.02963$, $\hat{s} = -5.59145\times10^{-9}$, $\hat{k} = 0.00173$, and $\hat{u} = 0.05730$ (Figure E.5). This tag-life survivorship model was subsequently used to estimate the probabilities of tag failure and provide tag-life-adjusted estimates of smolt survival.

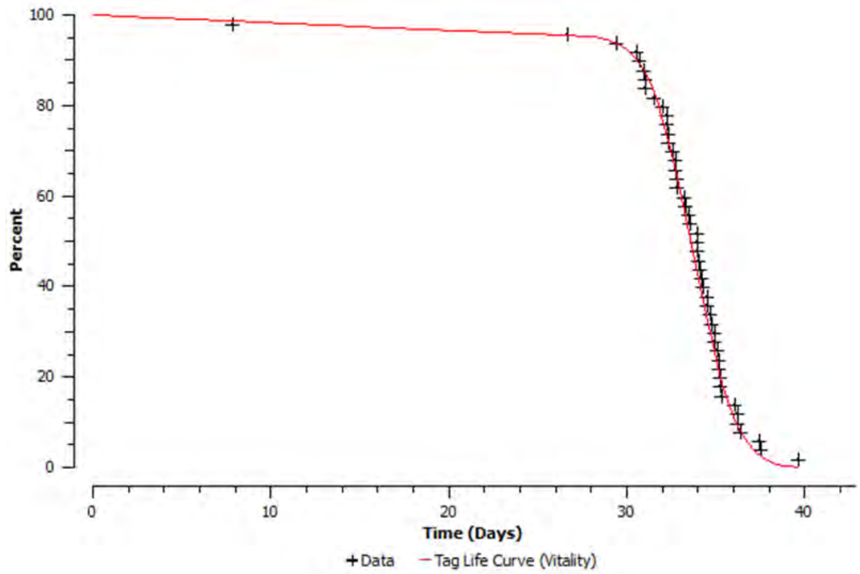


Figure E.5. Individual Failure Times for the n = 49 Acoustic Tags Used in the Tag-Life Study, Along with the Fitted Four-Parameter Vitality Model of Li and Anderson (2009) for Spring 2010

For the summer study, mean tag life (n = 50) was 35.54 d. The earliest tag failure was at 31.27 d and the latest at 40.13 d. The failure-time data for the acoustic tags was fit to a four-parameter vitality model of Li and Anderson (2009). The maximum likelihood estimates for the four model parameters were $\hat{r}$ = 0.028261, $\hat{s}$ = – 2.91111×10^{-9}, $\hat{k}$ = 0, and $\hat{u}$ = 0.058789 (Figure E.6). This tag-life survivorship model was subsequently used to estimate the probabilities of tag failure and provide tag-life-adjusted estimates of smolt survival.

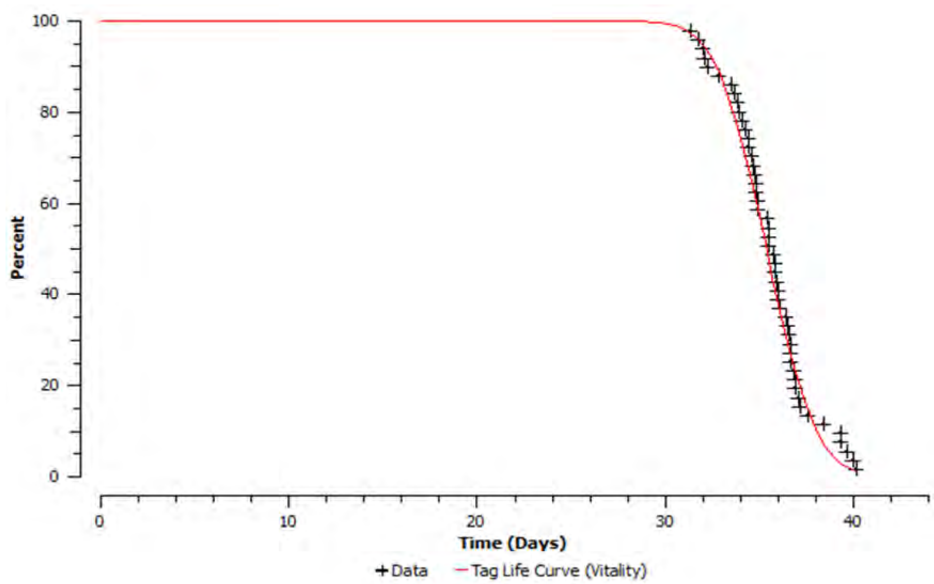


Figure E.6. Individual Failure Times for the n = 49 Acoustic Tags Used in the Tag-Life Study, Along with the Fitted Four-Parameter Vitality Model of Li and Anderson (2009) for Summer 2010

E.4 Arrival Distributions at Downstream Arrays

The estimated probability an acoustic tag was active when fish arrived at a downstream detection array depends on the tag-life curve and the distribution of observed travel times. These probabilities were calculated by integrating the tag survivorship curves (Figures E.5 and E.6) over the observed distribution of fish arrival times (i.e., time from tag activation to arrival) for the three tagged fish stocks separately. The estimated probabilities of tag activation for the various release groups at the different detection arrays always exceeded 0.98. The tag-life-adjusted survival estimates were based on the estimated probabilities of tag activation reported in Figures E.1, E.2, and E.3.

The last distinct detection array used in the survival analysis was rkm 153 (Figure 2.1). Plots of the arrival distributions of the three release groups (i.e., V_1, R_2, and R_3) to that array indicate the yearling Chinook salmon (Figure E.7), steelhead (Figure E.8), and subyearling Chinook salmon (Figure E.9) should have arrived well before tag failure became problematic. Tag-life adjustments to survival estimates would be incomplete if fish have arrival times beyond the range of observed tag lives.

Table E.1. Estimated Probabilities (*L*) of an Acoustic Tag Being Active When a Yearling Chinook Salmon Arrived at a Detection Array Used in Estimating Dam Passage Survival at The Dalles Dam in 2010. For the V_1 release, the *L* values are the conditional probability a tag is active, given it was active at the time the group was formed at detection array at rkm 309. (Standard errors are in parentheses.)

Release Group	Detection Sites					
	D2: Rkm 275	D3: Rkm 234	D4: Rkm 153	D5: Rkm 113	D6: Rkm 86	Rkm (49–3)
V_1	0.9990 (0.000511)	0.9978 (0.001086)	0.9960 (0.001989)	0.9951 (0.002400)	0.9945 (0.002684)	0.9934 (0.003216)
R_2	--	0.9901 (0.004844)	0.9881 (0.005820)	0.9874 (0.006188)	0.9867 (0.006487)	0.9857 (0.007012)
R_3	--	0.9910 (0.004397)	0.9891 (0.005357)	0.9881 (0.005804)	0.9876 (0.006062)	0.9865 (0.006597)

Table E.2. Estimated Probabilities (*L*) of an Acoustic Tag Being Active When a Steelhead Arrived at a Detection Array Used in Estimating Dam Passage Survival at The Dalles Dam in 2010. For the V_1 release, the *L* values are the conditional probability a tag is active, given it was active at the time the group was formed at detection array at rkm 309. (Standard errors are in parentheses.)

Release Group	Detection Sites					
	D_2: Rkm 275	D_3: Rkm 234	D_4: Rkm 153	D_5: Rkm 113	D_6: Rkm 86	Rkm (49–3)
V_1	0.9989 (0.000541)	0.9978 (0.001060)	0.9959 (0.002008)	0.9950 (0.002428)	0.9945 (0.002677)	0.9934 (0.003178)
R_2	--	0.9900 (0.004851)	0.9880 (0.005816)	0.9872 (0.006246)	0.9867 (0.006464)	0.9856 (0.006984)
R_3	--	0.9907 (0.004527)	0.9889 (0.005422)	0.9879 (0.005884)	0.9874 (0.006119)	0.9863 (0.006662)

Table E.3. Estimated Probabilities (L) of an Acoustic Tag Being Active When a Subyearling Chinook Salmon Arrived at a Detection Array Used in Estimating Dam Passage Survival at The Dalles Dam in 2010. For the V_1 release, the L values are the conditional probability a tag is active, given it was active at the time the group was formed at detection array at rkm 309. (Standard errors are in parentheses.)

Release	Detection Sites					
Group	D2: Rkm 275	D3: Rkm 234	D4: Rkm 153	D5: Rkm 113	D6: Rkm 86	Rkm (49–3)
V_1	1.0000 (0.000200)	1.0000 (0.000432)	1.0000 (0.000774)	1.0000 (0.000922)	0.9999 (0.001027)	0.9999 (0.001232)
R_2	--	1.0000 (0.000863)	1.0000 (0.001224)	1.0000 (0.001386)	1.0000 (0.001495)	1.0000 (0.001706)
R_3	--	1.0000 (0.000707)	1.0000 (0.001076)	1.0000 (0.001239)	1.0000 (0.001360)	1.0000 (0.001569)

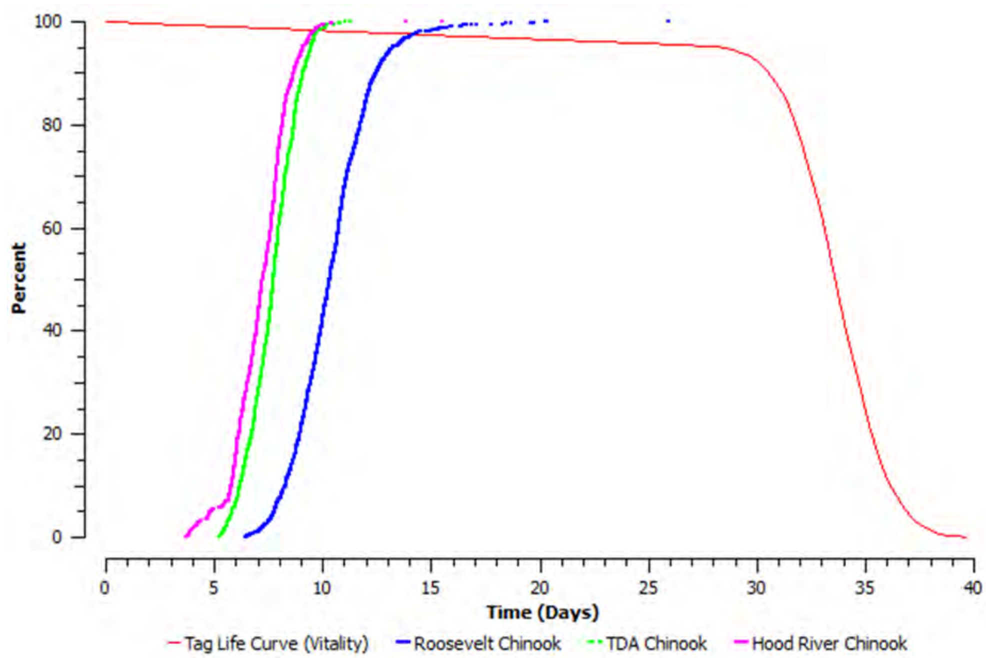


Figure E.7. Plot of the Fitted Tag-Life Survivorship Curve and the Arrival-Time Distributions of Yearling Chinook Salmon for Releases V_1, R_2, and R_3 at the Acoustic-Detection Array Located at rkm 153 (Table 2.4)

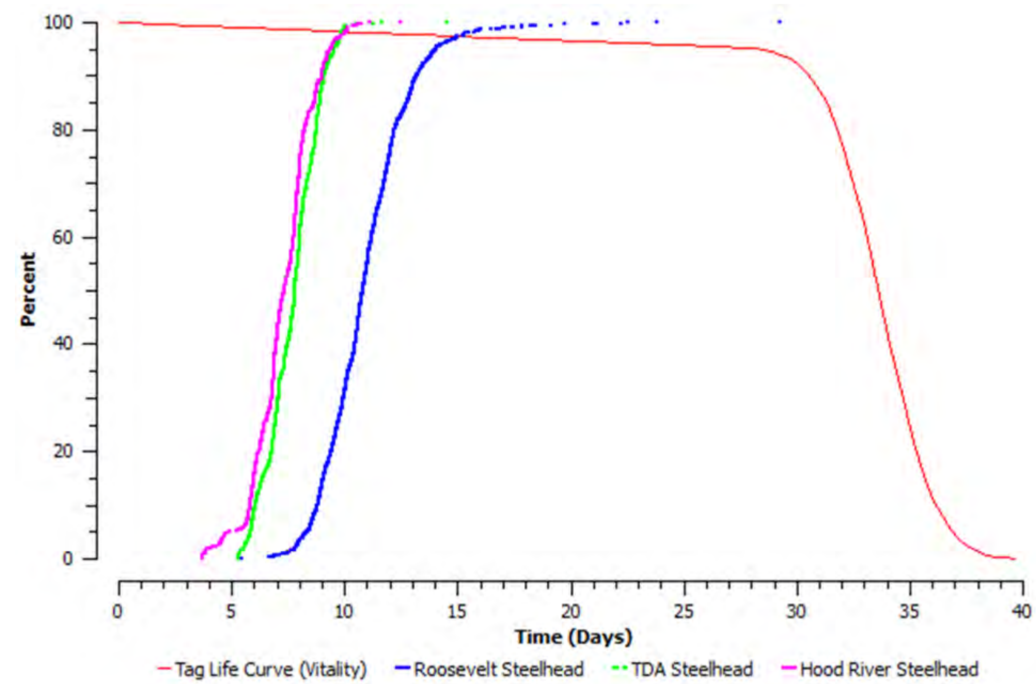


Figure E.8. Plot of the Fitted Tag-Life Survivorship Curve and the Arrival-Time Distributions of Steelhead for Releases V_1, R_2, and R_3 at the Acoustic-Detection Array Located at rkm 153 (Table 2.4)

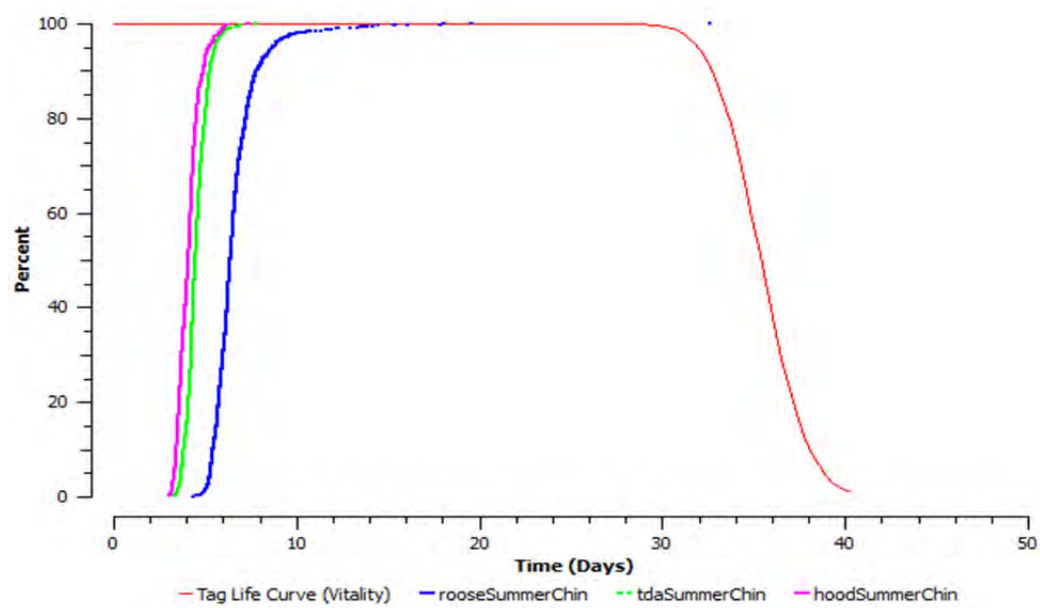


Figure E.9. Plot of the Fitted Tag-Life Survivorship Curve and the Arrival-Time Distributions of Subyearling Chinook Salmon for Releases V_1, R_2, and R_3 at the Acoustic-Detection Array Located at rkm 153 (Table 2.4)

E.5 Downstream Mixing

To help induce downstream mixing of the release groups, the R_1 release for yearling Chinook salmon and steelhead was 60 h before the R_2 release which, in turn, occurred 15 h before R_3. Release timing for subyearling Chinook salmon was similar except the R_2 release occurred 13 h before R_3. Plots of the frequency distribution of the arrival timing of the various release groups at downstream detection sites indicate reasonable mixing for yearling Chinook salmon (Figure E.10), steelhead (Figure E.11) and subyearling Chinook salmon (Figure E.12). The survival modes for releases R_2 and R_3 were nearly synchronous for all three tagged species. The modes for R_2 and R_3 were slightly later than the arrival mode for V_1 but during the majority of the distribution of arrival times for V_1 (Figures E.11 and E.12).

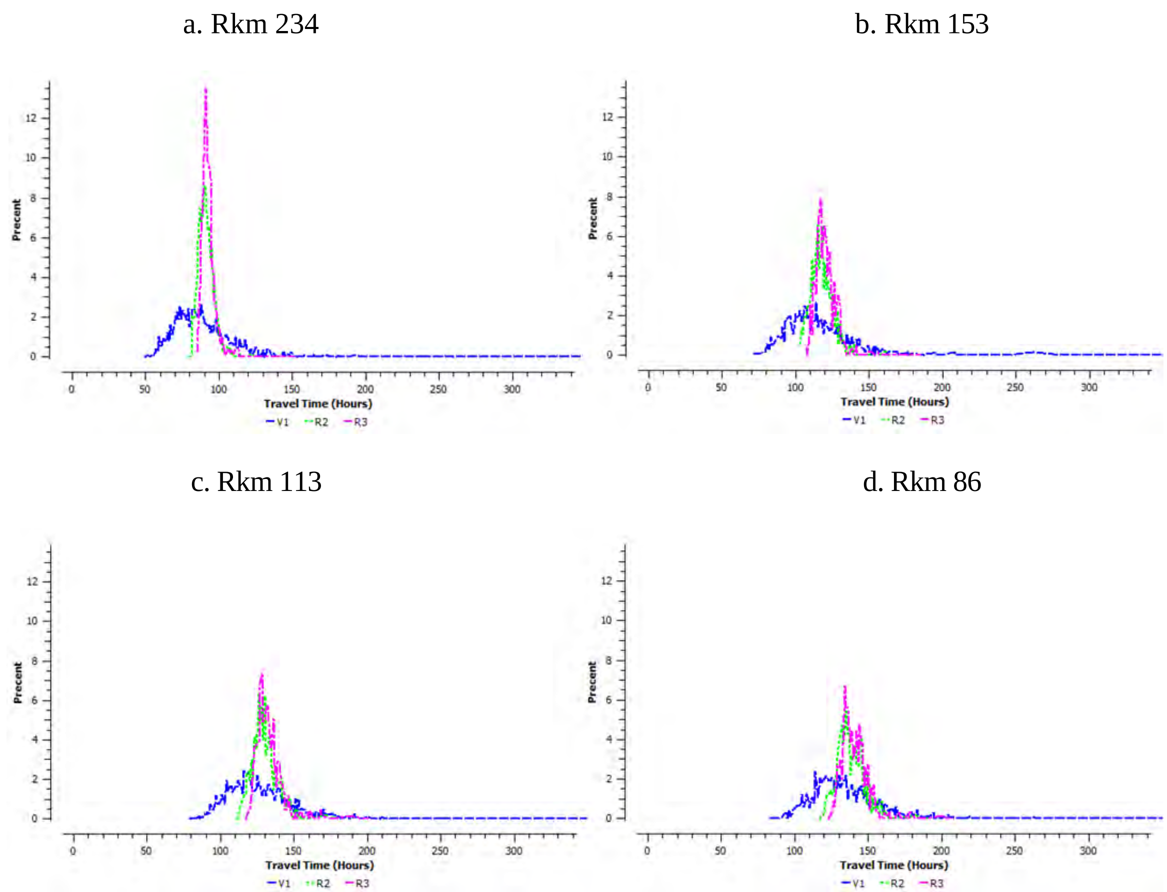


Figure E.10. Frequency Distribution Plots of Downstream Arrival Timing (Expressed as Percentages) for Yearling Chinook Salmon Releases V_1, R_2, and R_3 at Detection Arrays Located at a) rkm 234, b), rkm 153, c) rkm 113, and d) rkm 86. All times adjusted relative to the release time of V_1. The distributions averaged over all release groups.

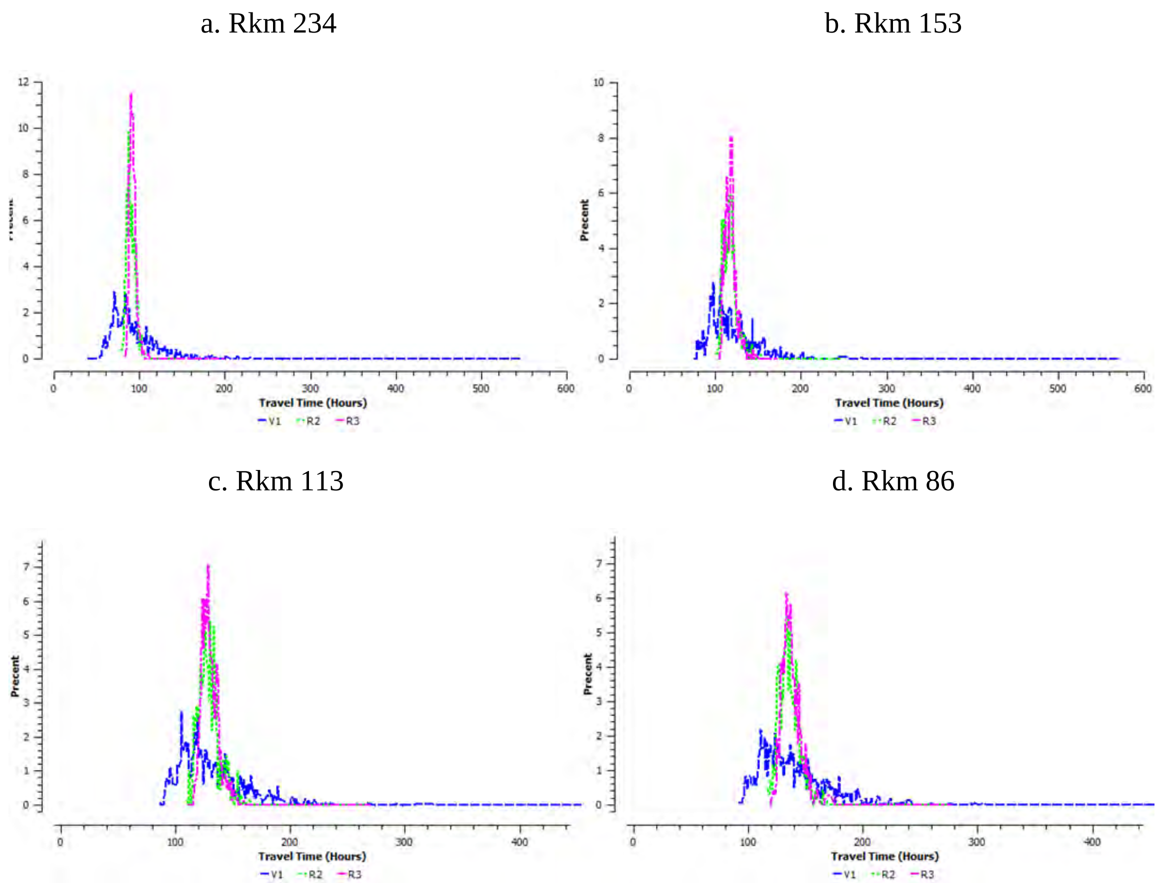


Figure E.11. Frequency Distribution Plots of Downstream Arriving Timing (Expressed as Percentages) for Steelhead Releases V_1, R_2, and R_3 at Detection Arrays Located at a) rkm 234, b) rkm 153, c) rkm 113, and d) rkm 86. All times adjusted relative to the release time of V_1. The distributions averaged over all release groups.

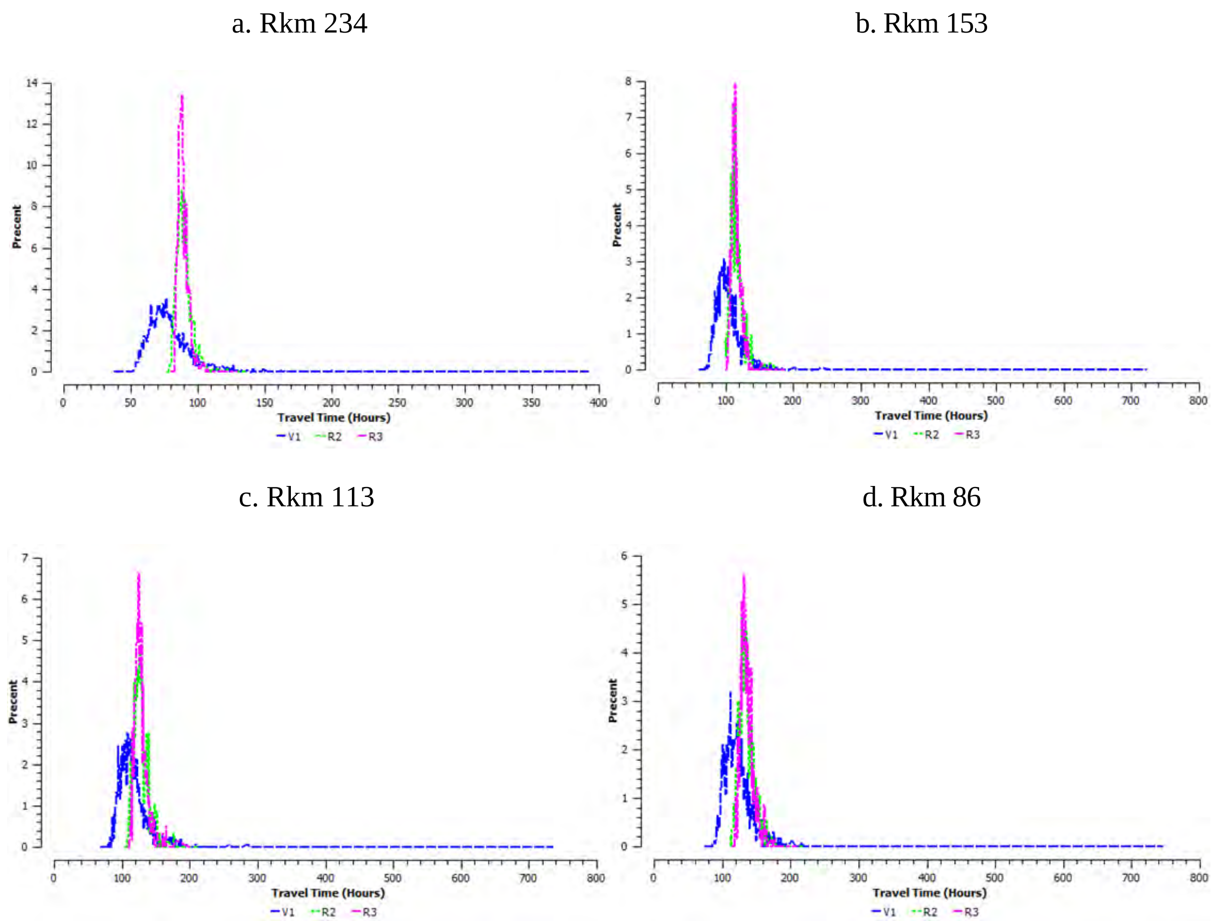


Figure E.12. Frequency Distribution Plots of Downstream Arriving Timing (Expressed as Percentages) for Subyearling Chinook Salmon Releases V_1, R_2, and R_3 at Detection Arrays Located at a) rkm 234, b) rkm 153, c) rkm 113, and d) rkm 86. All times adjusted relative to the release time of V_1. The distributions averaged over all release groups.

E.6 Tagger Effects

Having various fish handlers tag the same proportions of fish for release at each of the release sites helped minimize but did not necessarily eliminate handling effects in the survival study. The study was therefore designed to balance tagger effort across locations. Implementation produced nearly perfect balance for the yearling Chinook salmon (Table E.3), steelhead (Table E.4), and subyearling Chinook salmon (Table E.5) releases.

To further assess whether tagger effects may have occurred, reach survivals for the fish tagged by the different staff were calculated using the Cormack-Jolly Seber single release-recapture model. For both yearling Chinook salmon (Table E.6) and steelhead (Table E.7), reach survivals were found to be homogeneous ($P > 0.05$) across all reaches examined. For this reason, all fish, regardless of fish tagger, were included in the survival analyses for yearling Chinook salmon and steelhead.

For subyearling Chinook salmon, significant ($P < 0.05$) heterogeneity was detected (Table E.8). However, further examination indicated that seasonal trends in survival were confounding attempts to assess the presence of tagger effects using the *F*-tests because the effect of the various taggers was not evenly distributed across the course of the study. Fish tagged by tagger #7 had lower survivals because that staff member only tagged fish towards the end of the season. Fish tagged by tagger #2 had very good survival because that staff member only tagged fish at the beginning of the study. The remaining taggers had fish with intermediate survivals because they tagged fish more or less across the breadth of the season. The fish tagged by different staff during the same time were examined; survivals were homogeneous with no obvious evidence of any tagger effect. Therefore, fish tagged by all taggers were included in the analysis for this report.

Table E.4. Number of Yearling Chinook Salmon Tagged at Each Release Site by Tagger. Tagger effort was homogeneous $\left(P\left(\chi^2_{10} \geq 1.0336\right) = 0.9998\right)$.

	Tagger						
Release Location	#1	#2	#3	#4	#5	#6	Total
R_1	441	356	311	350	372	457	2287
R_2	149	123	110	129	124	161	796
R_3	152	126	109	117	130	163	797
Total Tags	742	605	530	596	626	781	3880

Table E.5. Number of Steelhead Tagged at Each Release Site by Tagger. Tagger effort was homogeneous $\left(P\left(\chi^2_{10} \geq 0.5851\right) = 1.0000\right)$.

	Tagger						
Release Location	#1	#2	#3	#4	#5	#6	Total
R_1	430	359	331	354	365	449	2288
R_2	155	124	114	126	125	155	799
R_3	157	121	112	126	126	156	798
Total Tags	742	604	557	606	616	760	3885

Table E.6. Number of Subyearling Chinook Salmon Tagged at Each Release Site by Tagger. Tagger effort was homogeneous $\left(P\left(\chi^2_{12} \geq 8.6496\right) = 0.7325\right)$.

	Tagger							
Release Location	#1	#2	#3	#4	#5	#6	#7	Total
R_1	436	489	463	454	171	369	467	2,849
R_2	132	135	116	123	40	108	146	800
R_3	131	133	128	119	35	115	139	800
Total Tags	699	757	707	696	246	592	752	4,449

Table E.7. Cormack-Jolly-Seber Estimates of Reach Survivals by Release Site and Tagger for Yearling Chinook Salmon Smolts. Standard errors in parentheses. *F*-tests below each release and reach test for homogeneity of survival across taggers. No tests were significant (α < 0.05).

Release Site	Tagger	Cormack-Jolly-Seber Survival					
		Release to Rkm 309	Rkm 309 to 275	Rkm 275 to 234	Rkm 234 to 153	Rkm 153 to 113	Rkm 113 to 86
Roosevelt Chinook	#1	0.8912 (0.0148)	0.9364 (0.0123)	0.9790 (0.0076)	0.9165 (0.0147)	0.9975 (0.0034)	1.0000 (<0.0001)
	#2	0.8934 (0.0164)	0.9527 (0.0119)	0.9910 (0.0057)	0.9512 (0.0134)	0.9790 (0.0102)	1.0000 (<0.0001)
	#3	0.8489 (0.0203)	0.9318 (0.0155)	0.9797 (0.0090)	0.9554 (0.0135)	0.9953 (0.0054)	1.0000 (<0.0001)
	#4	0.8943 (0.0164)	0.9457 (0.0128)	0.9767 (0.0088)	0.9383 (0.0148)	0.9789 (0.0102)	0.9917 (0.0141)
	#5	0.9140 (0.0145)	0.9382 (0.0131)	0.9906 (0.0053)	0.9215 (0.0152)	0.9985 (0.0048)	0.9899 (0.0131)
	#6	0.9059 (0.0137)	0.9348 (0.0121)	0.9798 (0.0072)	0.9282 (0.0136)	0.9880 (0.0070)	1.0000 (0.0165)
	F-test	1.9448	0.3597	0.7243	1.2466	1.5091	0.2137
	P-value	0.0828	0.8763	0.6051	0.2840	0.1832	0.9569
			Release to Rkm 275	Rkm 275 to 234	Rkm 234 to 153	Rkm 153 to 113	Rkm 113 to 86
The Dalles Dam Chinook	#1		0.9731 (0.0132)	0.9798 (0.0118)	0.9295 (0.0216)	1.0000 (0.0073)	1.0000 (<0.0001)
	#2		0.9756 (0.0139)	0.9750 (0.0142)	0.9403 (0.0219)	1.0000 (<0.0001)	1.0000 (0.0260)
	#3		0.9909 (0.0089)	0.9821 (0.0128)	0.9534 (0.0206)	1.0000 (<0.0001)	0.9986 (0.0403)
	#4		0.9690 (0.0152)	0.9760 (0.0137)	0.9275 (0.0237)	0.9916 (0.0101)	0.9933 (0.0230)
	#5		0.9919 (0.0079)	0.9756 (0.0139)	0.9419 (0.0214)	1.0000 (0.0145)	0.9795 (0.0180)
	#6		0.9813 (0.0106)	0.9943 (0.0062)	0.9568 (0.0168)	0.9925 (0.0086)	1.0000 (<0.0001)
	F-test		0.6328	0.3480	0.3221	0.2312	0.1259
	P-value		0.6747	0.8838	0.9000	0.9490	0.9866
				Release to Rkm 234	Rkm 234 to 153	Rkm 153 to 113	Rkm 113 to 86
Hood River Chinook	#1			0.9737 (0.0130)	0.9599 (0.0162)	1.0000 (0.0083)	1.0000 (<0.0001)
	#2			0.9921 (0.0078)	0.9710 (0.0159)	0.9821 (0.0138)	1.0000 (<0.0001)
	#3			0.9816 (0.0128)	0.9445 (0.0223)	1.0000 (<0.0001)	1.0000 (<0.0001)
	#4			0.9829 (0.0119)	0.9485 (0.0207)	1.0000 (<0.0001)	0.9841 (0.0356)
	#5			0.9923 (0.0076)	0.9473 (0.0200)	0.9928 (0.0098)	1.0000 (0.0305)
	#6			0.9945 (0.0060)	0.9510 (0.0172)	1.0000 (<0.0001)	0.9440 (0.0242)
	F-test			0.1386	0.2795	0.9024	0.6280
	P-value			0.9834	0.9246	0.4783	0.6784

Table E.8. Cormack-Jolly-Seber Estimates of Reach Survivals by Release Site and Tagger for Steelhead Smolts. Standard errors in parentheses. *F*-tests below each release and reach test for homogeneity of survival across taggers. No tests were significant (α < 0.05).

		Cormack-Jolly-Seber Survivals					
Release Site	Tagger	Release to Rkm 309	Rkm 309 to 275	Rkm 275 to 234	Rkm 234 to 153	Rkm 153 to 113	Rkm 113 to 86
Roosevelt Steelhead	#1	0.8930 (0.0149)	0.9505 (0.0111)	0.9699 (0.0089)	0.9107 (0.0153)	0.9978 (0.0041)	1.0000 (<0.0001)
	#2	0.8831 (0.0170)	0.9621 (0.0107)	0.9671 (0.0102)	0.9131 (0.0166)	1.0000 (0.0083)	0.9869 (0.0225)
	#3	0.9063 (0.0160)	0.9600 (0.0113)	0.9831 (0.0077)	0.8978 (0.0186)	0.9824 (0.0102)	1.0000 (<0.0001)
	#4	0.8729 (0.0177)	0.9320 (0.0143)	0.9725 (0.0097)	0.9479 (0.0149)	0.9683 (0.0134)	0.9934 (0.0254)
	#5	0.9151 (0.0146)	0.9372 (0.0133)	0.9776 (0.0084)	0.9069 (0.0172)	0.9805 (0.0105)	0.9737 (0.0208)
	#6	0.9065 (0.0137)	0.9656 (0.0090)	0.9804 (0.0072)	0.9118 (0.0149)	0.9892 (0.0076)	0.9895 (0.0239)
	F-test	1.0452	1.4044	0.5128	1.1099	1.5660	0.2701
	P-value	0.3890	0.2192	0.7668	0.3525	0.1659	0.9297
			Release to Rkm 275	Rkm 275 to 234	Rkm 234 to 153	Rkm 153 to 113	Rkm 113 to 86
The Dalles dam Steelhead	#1		0.9806 (0.0110)	0.9803 (0.0113)	0.9333 (0.0205)	1.0000 (<0.0001)	0.9967 (0.0345)
	#2		0.9758 (0.0138)	0.9752 (0.0141)	0.9527 (0.0205)	0.9805 (0.0151)	0.9944 (0.0206)
	#3		0.9912 (0.0087)	0.9734 (0.0151)	0.9478 (0.0218)	0.9902 (0.0120)	1.0000 (<0.0001)
	#4		0.9920 (0.0078)	0.9840 (0.0112)	0.9843 (0.0114)	1.0000 (0.0075)	1.0000 (<0.0001)
	#5		0.9920 (0.0078)	0.9919 (0.0079)	0.9504 (0.0215)	0.9673 (0.0189)	0.9905 (0.0096)
	#6		0.9742 (0.0127)	1.0000 (<0.0001)	0.9781 (0.0135)	0.9855 (0.0129)	0.9594 (0.0224)
	F-test		0.6342	0.8435	1.0881	0.9839	0.6524
	P-value		0.6736	0.5185	0.3646	0.4258	0.6597
				Release to Rkm 234	Rkm 234 to 153	Rkm 153 to 113	Rkm 113 to 86
Hood River Steelhead	#1			0.9745 (0.0126)	0.9416 (0.0190)	1.0000 (<0.0001)	1.0000 (<0.0001)
	#2			0.9669 (0.0162)	0.9600 (0.0190)	0.9891 (0.0117)	1.0000 (<0.0001)
	#3			0.9732 (0.0152)	0.9565 (0.0202)	0.9900 (0.0120)	1.0000 (<0.0001)
	#4			0.9687 (0.0156)	0.9429 (0.0212)	1.0000 (<0.0001)	0.9875 (0.0238)
	#5			0.9920 (0.0078)	0.9785 (0.0140)	0.9945 (0.0110)	1.0000 (<0.0001)
	#6			0.9430 (0.0187)	0.9151 (0.0239)	0.9846 (0.0138)	0.9620 (0.0314)
	F-test			1.1524	1.1703	0.3951	0.9084
	P-value			0.3303	0.3211	0.8525	0.4743

Table E.9. Cormack-Jolly-Seber Estimates of Reach Survivals by Release Site and Tagger for Subyearling Chinook Salmon. Standard errors in parentheses. *F*-tests below each release and reach test for homogeneity of survival across taggers. No tests were significant (α < 0.05).

Release Site	Tagger	Release to Rkm 309 Estimate	Release to Rkm 309 SE	Rkm 309 to 275 Estimate	Rkm 309 to 275 SE	Rkm 275 to 234 Estimate	Rkm 275 to 234 SE	Rkm 234 to 153 Estimate	Rkm 234 to 153 SE	Rkm 153 to 113 Estimate	Rkm 153 to 113 SE	Rkm 113 to 86 Estimate	Rkm 113 to 86 SE
		Cormack-Jolly-Seber Survival											
R_1	A	0.8395 (5)	0.0177	0.9141 (4)	0.0147	0.9671 (5)	0.0104	0.9426 (4)	0.0138	0.9810 (4)	0.0086	0.9912 (4)	0.0061
	B	0.8938 (2)	0.0141	0.9394 (3)	0.0115	1.0000 (2)	0.0044	0.9592 (2)	0.0102	0.9909 (2)	0.0052	0.9980 (3)	0.0023
	C	0.8522 (4)	0.0165	0.9465 (2)	0.0114	1.0000 (2)	0.0000	0.9195 (5)	0.0142	0.9965 (1)	0.0034	0.9989 (2)	0.0045
	D	0.8027 (6)	0.0187	0.9033 (5)	0.0155	0.9520 (6)	0.0124	0.9126 (6)	0.0168	0.9732 (5)	0.0106	0.9746 (6)	0.0101
	E	0.9357 (1)	0.0188	0.9562 (1)	0.0162	1.0000 (2)	0.0000	0.9782 (1)	0.0133	0.9822 (3)	0.0125	1.0000 (1)	0.0096
	F	0.8910 (3)	0.0163	0.9016 (6)	0.0165	0.9879 (4)	0.0068	0.9500 (3)	0.0135	0.9722 (6)	0.0107	0.9787 (5)	0.0094
	G	0.7795 (7)	0.0194	0.8908 (7)	0.0165	0.9515 (7)	0.0138	0.8806 (7)	0.0198	0.9692 (7)	0.0111	0.9648 (7)	0.0117
All Taggers	*F*-test	9.8531		2.9625		6.8130		4.9085		1.1627		2.8155	
	P-value	<0.0001		0.0068		<0.0001		<0.0001		0.3229		0.0097	
Tagger G Omitted	*F*-test	7.5949		2.6425		7.6624		3.1904		1.1168		2.1171	
	P-value	<0.0001		0.0215		<0.0001		0.0070		0.3487		0.0603	

Release Site	Tagger	Release 309 to 275 Estimate	Release 309 to 275 SE	Rkm 275 to 234 Estimate	Rkm 275 to 234 SE	Rkm 234 to 153 Estimate	Rkm 234 to 153 SE	Rkm 153 to 113 Estimate	Rkm 153 to 113 SE	Rkm 113 to 86 Estimate	Rkm 113 to 86 SE
		Cormack-Jolly-Seber Survival									
R_2	A	0.9924 (3)	0.0074	0.9807 (5)	0.0132	0.9511 (5)	0.0201	0.9925 (4.5)	0.0098	0.9761 (4)	0.0155
	B	0.9704 (7)	0.0146	0.9874 (2)	0.0108	0.9619 (4)	0.0183	0.9814 (6)	0.0136	0.9842 (3)	0.0121
	C	0.9914 (5)	0.0085	0.9806 (6)	0.0153	0.9421 (6)	0.0239	0.9925 (4.5)	0.0118	0.9511 (7)	0.0226
	D	0.9918 (4)	0.0080	0.9867 (3)	0.0116	0.9637 (3)	0.0178	1.0000 (2)	0.0175	0.9671 (5)	0.0170
	E	1.0000 (1.5)	0.0071	1.0000 (1)	0.0071	0.9750 (2)	0.0247	1.0000 (2)	0.0084	1.0000 (1.5)	0.0072
	F	1.0000 (1.5)	0.0000	0.9819 (4)	0.0129	0.9902 (1)	0.0097	1.0000 (2)	0.0000	1.0000 (1.5)	0.0000
	G	0.9795 (6)	0.0117	0.9785 (7)	0.0142	0.9226 (7)	0.0237	0.9777 (7)	0.0137	0.9592 (6)	0.0181
All Taggers	*F*-test	1.3856		0.3499		1.1805		0.6034		1.6362	
	P-value	0.2159		0.9103		0.3130		0.7279		0.1326	
Tagger G Omitted	*F*-test	1.5552		0.3728		0.7505		0.4070		1.7774	
	P-value	0.1691		0.8676		0.5856		0.8443		0.1138	

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